



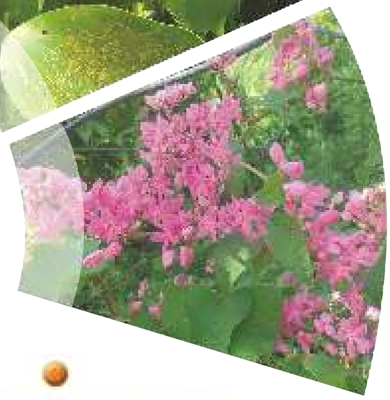


Invasive Species

A Handbook

Indian Council of Forestry Research & Education

(An autonomous body of Ministry of Environment, Forest & Climate Change, Government of India)

INVASIVE SPECIES

A HANDBOOK

INDIAN COUNCIL OF FORESTRY RESEARCH AND EDUCATION
P.O. New Forest, Dehradun - 248 006

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Foreword

Dr. Suresh Gairola, IFS
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Forestry Research and Educatrion

ICFRE with its Headquarters at Dehradun is an apex body in the national forestry research system that promotes and undertakes need based forestry research and extension. The Council that came into being in 1986 has a pan India presence with its 9 Regional Research Institutes and 5 Centers in different bio-geographical regions of the country. Since then research in different fields of forestry has been a major focus of ICFRE.

There is an earnest need to present its research findings to the stakeholders in a simple and lucid manner to improve the visibility and relevance of ICFRE. Therefore, it was decided that the information available on the technologies, processes, protocols and practices developed by ICFRE be published in the form of operational manuals/user manuals. It is also desirable that the manual should be a comprehensive national level document depicting extent of knowledge in applicable form.

Accordingly, 18 scientists of ICFRE were nominated as National Subject Matter Coordinators (NSMCs) to carry out the task on the specified subject. These NSMCs were assigned the task to select and nominate nodal officers from other Institutes of ICFRE as well as other organizations if necessary, collect and collate the information on the subject from various sources in coordination with the nodal officers of ICFRE institutes.

The handbook on Invasive Alien Species is required essentially as these species are widely recognized as a significant component of human-caused global environmental change and the second most important cause of biodiversity decline. Alien species threaten many Indian forest ecosystems and have serious environmental, economic and health impacts. I am pleased to inform that this book has now brought together all available information on Invasive Alien Species in forests of India and it will be the basis for future scientific investigations as well as management and control of alien invasive species in India.

I congratulate the efforts made by the authors and I am sure that this publication will prove effective to all the people working towards the conservation and sustainable management of native biodiversity in the country.

Dr. Suresh Gairola

Preface

Invasive Alien Species (IAS) are regarded as one of the major causes for species extinction, global environment changes, loss of biodiversity and disruption of ecosystem processes essential for human welfare. Understanding the negative impacts of invasive alien species, pathways should be identified and prioritized, priority species should be controlled or eradicated, and measures should be taken to manage pathways for preventing their introduction and establishment (Aichi Biodiversity Targets by 2020). However to achieve this target presently, there is inadequate information about invasive alien plants species in the country. Also, scientists, policy-makers and researchers require access to information to assist control and mitigate the effects of invasive species. Further, it is important to create awareness and implement proper legislation and policy framework for the control and management of invasive species.

This handbook is a collaborative effort of the various scientists and researchers working in different institutes of Indian Council of Forestry Research and Education (ICFRE), Dehradun. The book covers various topics such as, status and documentation, spatial mapping and modelling, ecological impacts, control and management, utilisation potential and policy challenges in the management of IAS. It highlights existing invasive alien species, evaluates the level of risk they pose to native species and suggests steps to manage their spread and some key points for restoration models in the invaded areas. The publication will broaden our understanding of the complexity of the issue of invasive alien species and at the same time facilitate the implementation of remedial measures to reduce or halt biodiversity loss attributed to invasive alien species. This book will also serve as a necessary reading manual for researchers, forest managers, policy makers, general public and students.

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The authors of the handbook would like to acknowledge with much appreciation the crucial role of Dr. S. C. Gairola, IFS, Director General ICFRE, who has suggested the topic to prepare the book on Invasive Alien Species and gave the approval to use all the necessary facilities and infrastructure in the council to complete the task. The authors of the book thank the Directors of Forest Research Institute (FRI), Dehradun, Institute of Forest Genetics & Tree Breeding (IFGTB), Coimbatore, Institute of Wood Science & Technology (IWST), Bengaluru, Tropical Forest Research Institute (TFRI), Jabalpur, Rain Forest Research Institute (RFRI), Jorhat, Arid Forest Research Institute (AFRI), Jodhpur and Institute of Forest Productivity (IFP), Ranchi for providing all the necessary support to prepare the book. The authors of the book also thank the Editorial Board for approving the book for publication. Last but not least, many thanks go to the staff and Research Scholars of Forest Ecology and Climate Change Division, IFGTB for their help in finalizing the book.

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TARGET GROUP

State Forest Departments, policy makers, Scientists, other Researchers

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1 DOCUMENTATION AND STATUS OF INVASIVE ALIEN PLANT SPECIES IN INDIA

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INTRODUCTION

Number of alien plants have been introduced into India either intentionally or unintentionally at a very early period and some of them are integrated with the cultural history of India. However, out of the many introduced species some become invasive and problematic. This introduction of alien species takes place through different pathways such as release, escape, transport-contaminants, transport-stowaway, corridors and unaided (natural dispersers). Technically an alien plant is an exotic, non-indigenous, introduced, foreign, or non native plant species introduced by humans intentionally or otherwise through human agency accidently from different regions. If new habitat of introduced species is similar enough to its native range, it grows profusely and ultimately becomes an invasive species in that particular area. Sometime their history of origin and distribution might not be clear but their global expansion and distribution is accelerated due to global trade and human mobility (Meyerson and Mooney, 2007). The saga of invasive species involves successive arrival, successfully out competing native species, surviving in all possible ranges, thriving at their best and gradually replacing the native flora through required adaptation. These species possess some peculiar characteristics such as rapid reproduction and growth, intense dispersal capacity, highly adaptive nature, capability to survive in diverse ecological regions, tolerant to a wide range of edaphic and climatic conditions, produce copious amount of seeds that disperse easily, high dispersal rate, long flowering and fruiting periods, grows aggressive root systems, short generation time, and broad native range (Reddy *et al.*, 2008). The ecological interactions between alien and native species are complex and still there is huge knowledge gap about this. The invasion of alien plants into natural or previously un-invaded habitats involves a number of significant changes to the habitat, often negatively affecting resident flora as well as fauna. Alien plants may directly modify the structure and complexity of the physical environment (Trullas and Garcia, 2017). An alien plant species that reaches a high abundance and dominates an ecosystem will potentially influence the performance of individual resident species and their population dynamics (Vila and Weiner, 2004). Hence these species possess potentially greater capabilities to affect the ecosystem directly as well as indirectly.

UNDERSTANDING THE TERMS

The understanding and management of invasive Alien Species (IAS) is an emerging science and its terminologies continue to evolve and change. Terms such as alien, invasive, weed, introduced, feral and exotic are sometimes used to describe invasive species (ISSG 2015). Some important definitions related to invasive species are given in Box 1.

Box 1. Important Definitions related to invasive species.

The definitions adopted by Decision VI/23 of the Conference of the Parties to the Convention on Biological Diversity at its sixth meeting, The Hague, 7–19 April 2002 (CBD 2002) are as follows;

“alien species” refers to a species, subspecies or lower taxon, introduced outside its natural past or present distribution; includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce;

“invasive alien species” means an alien species whose introduction and/or spread threaten biological diversity (For the purposes of the present guiding principles, the term "invasive alien species" shall be deemed the same as "alien invasive species" in decision V/8 of the Conference of the Parties to the Convention on Biological Diversity);

“introduction” refers to the movement by human agency, indirect or direct, of an alien species outside of its natural range (past or present). This movement can be either within a country or between countries or areas beyond national jurisdiction;

“establishment” refers to the process of an alien species in a new habitat successfully producing viable offspring with the likelihood of continued survival;

“risk analysis” refers to: (1) the assessment of the consequences of the introduction and of the likelihood of establishment of an alien species using science-based information (i.e., risk assessment), and (2) the identification of measures that can be implemented to reduce or manage these risks (i.e., risk management), taking into account socio-economic and cultural considerations.

Source: (CBD 2002).

Pathways

A pathway is broadly defined as the means (e.g. aircraft, vessel or person), purpose or activity (e.g. farming, shipping or pet trade), or a commodity (e.g. fisheries) by which an alien species may be transported to a new location, either intentionally or unintentionally (ISSG 2015). As mentioned earlier, it can be hitchhiking, transport through trades as in the case of Parthenium introduction in India. Natural dispersal also plays a significant role in the subsequent spreading of an alien species once introduced to a new region or country (ISSG 2015).

Invasion hypotheses

Several major hypotheses have been proposed to explain and predict biological invasions, but the general applicability of these hypotheses is largely unknown, as most of them have not been evaluated using a standard approach across taxonomic groups and environment (Davis *et al.*, 2000). The summary of the various hypotheses behind biological invasion is summarized in Table.1.

Table 1. *Major hypotheses for the success of exotic plants in recipient communities.*

Hypothesis name	Definition	References
Natural enemies	States that exotics are relieved from natural enemies which control their population growth	Darwin (1859), Williams(1954), Elton (1958)
Evolution of invasiveness	Exotics experience rapid genetic changes linked to new selection pressures in the novel environment	Blossey and Nötzold (1995), Lee (2002), Stockwell *et al.* (2003)
Empty niche	According to empty niche hypothesis exotics utilize resources which remain unused by the locals	Elton (1958), MacArthur (1970)
Novel weapons	In novel weapons hypothesis exotics produce some kind of novel ways of biochemical which harm the native environment	Callaway and Aschehoug (2000), Bais *et al.* 2003
Disturbance	Exotics are capable to adapt to disturbances type and intensity that are novel to natives	Gray (1879), Baker (1974)
Species richness	Communities which are Species-rich are more resistant towards invasion as compared to communities with lesser species	Elton (1958), MacArthur (1970,1972)
Propagule pressure	Variations in levels of invasion among recipient communities are due to differences in the number of exotics arriving in the community	di Castri (1989), Williamson (1996), Lonsdale (1999)

(Source: Hierro et al., 2005)

WHAT MAKES A SPECIES INVASIVE?

The introduction of plant species beyond their natural range is rising significantly and the reasons and different pathways of introduction we have seen earlier. Interestingly most of the alien plant species do not become an invasive species and not necessarily they are included in the list of alien invasive plant species. IUCN defines, an *invasive alien species (IAS) is a species that is established outside of its natural past or present distribution, whose introduction and/ or spread threaten biological diversity.* Though there is not an ideal set of parameters to put a species in invasive alien plant list, different researches have depicted results showing various characteristics of a particular species which holds significant potential to get the label of invasive species (Reddy *et al.*, 2008). These are as follows;

- Pioneer species in various landscapes
- Widely tolerant of different geographical ranges
- Generalist distribution habit

- Abundant seed production
- Easy and high dispersion
- Aggressive root system
- Long fruiting and flowering period
- Broad native range
- Abundant in native range
- Aggressive behaviour and competitive ability

Invasive Alien Plant Species (IAPS) exhibit greater abundance, density, or competitive dominance than species native to habitats (Singh and Sharma, 2014). Once established, early detection of spreading pattern and eradication of IAPS is more cost effective than long term control. Invasive plants species are the second most important threat to global biodiversity (Bhatt *et al.*, 2011). Understanding the necessity, Convention on Biological Diversity has already made efforts for the management of these species. Since most of the countries are party to Convention on Biodiversity (CBD), they have an obligation to manage Invasive alien species and priority actions guided by Aichi Target 9 *"By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated and measures are in place to manage pathways to prevent their introduction and establishment"* (IUCN, 2018). Aligning with this, India has set National Biodiversity Targets, including sub target focused on Invasive Alien Species (IAS). However, in India very few IAPS have been studied so far and comprehensive document is not yet available. Current regulatory approaches regarding IAPS in India is not enough to deal with this problem. Areas which are invaded by alien plant species and which are vulnerable to such invasion are yet not identified in different parts of India.

INVASIVE ALIEN PLANT SPECIES

International efforts

Invasive Alien Plant Species (IAPS) are a major threat to biological diversity on a global scale, necessitating international cooperation to address the problem. Global policy and decision makers have responded to the growing challenges posed by IAS with Multilateral Environment Agreements (MEAs), such as the Convention on Biological Diversity (CBD), Ramsar Convention on Wetlands and Sanitary and Phytosanitary measures of the International Plant Protection Convention (IPPC), all address aspects pertaining to invasive alien species, variously encouraging member States to prevent the introduction of alien and invasive species and to manage established populations. As mentioned earlier, Target 9 of the Aichi Biodiversity Targets in the CBD Strategic Plan for Biodiversity 2011–2020 is focused on invasive alien species (CBD 2010 and 2016). The Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services (IPBES) has also identified the need for a thematic global assessment on invasive alien species and their control (Deliverable 3(b)(ii); IPBES 2016). Some of the key international, regional and national initiatives promoting information-sharing on IAPS are given in Box 2.

Box 2. Key initiatives promoting information-sharing on IAPS

Key international Initiatives Promoting Information-sharing

- Global Invasive Species Information Network (GISIN)
- Global Invasive Species Database (GISD) of ISSG
- CAB International
- Global Register of Invasive Species (GRIS) of ISSG (website under development)
- NISbase
- Global Invasive Alien Species Information Partnership Information Gateway

Key Regional and National Networks and Initiatives

- Aquatic Invasive Alien Species Web portal for ASEAN countries
- Asia-Pacific Forest Invasive Species Network (APFISN)
- BioNET's regional networks
- CIESM Atlas of Exotic Species in the Mediterranean
- Delivering Alien Invasive Inventories for Europe (DAISIE)
- Forest Invasive Species Network for Africa – FISNA
- Inter-American Biodiversity Information Network
- National Introduced Marine Pest Information System NIMPIS – An information system for marine introductions in Australia.
- The North European and Baltic Network on Invasive Alien Species (NOBANIS)
- The North American Plant Protection Organization (NAPPO) Phytosanitary Alert System (PAS)
- European Plant Protection Organisation
- Regional Biological Invasions Centre (RBIC)
- USDA National Invasive Species Information Center
- European Alien Species Information Network

Source: https://www.cbd.int/invasive/database.shtml

- Invasive Species Specialist Group (ISSG) established in 1994 by the IUCN Species Survival Commission is a global network of scientific and policy experts on invasive species. The ISSG aims to reduce threats to natural ecosystems and the native species they contain by increasing awareness of invasive alien species and ways to prevent, control or eradicate them. The ISSG promotes and facilitates the exchange of invasive species information and knowledge across the globe and ensures the linkage between knowledge, practice and policy so that decision making is informed. The ISSG publishes a biannual newsletter 'Aliens'. 'Aliens' features articles on issues related to invasive species. The ISSG manages the Global Invasive Species Database (GISD) an online, freely available premier resource of information on invasive species, their ecology, spread, management and impacts. The ISSG manages Aliens-L, a list server dedicated to invasive species that threaten biodiversity. It allows users to freely seek and share information on invasive species and related issues. The ISSG also operates a dynamic resource and information service known as Aliens-Referral that has grown over the years, continuing to meet the needs of stakeholders. Aliens-Referral provides invasive species and related information to stakeholders on request and facilitates linkages between global experts and practitioners (ISSG 2015; IUCN, 2018).

- The Global Invasive Species Database (GISD) is a free, online searchable source of information about alien and invasive species that negatively impact biodiversity. The database is managed by the Invasive Species Specialist Group (ISSG) of the IUCN Species Survival Commission and it was developed as part of the global initiative on invasive species led by the erstwhile Global Invasive Species Programme (GISP). It aims to increase public awareness about invasive species and to facilitate effective prevention and management activities by disseminating specialist's knowledge and experience globally to a broad audience (ISSG 2015; IUCN, 2018).

- The Centre for Agriculture and Bioscience International (CABI) is a not-for-profit inter-governmental development and information organization focusing primarily on agricultural and environmental issues in the developing world. CABI has developed "The Invasive Species Compendium", which is an online, comprehensive encyclopedic reference work covering recognition, biology, distribution, impact and management of the world's invasive plants and animals. It offers extensive global coverage of invasive species from all taxonomic groups and ecosystems (excluding human pathogens), with fast and easy navigation between text, images, maps and databases. The Compendium is a vital tool for resource managers, extension workers, policymakers, researchers in the areas of agriculture and the environment, and border control import/export regulatory officers. It is freely available to all on an open access basis and is maintained, enhanced and regularly updated with hundreds of new and revised datasheets published each year, plus weekly additions of abstracts and full text articles (https://www.cabi.org).

  The International Association for Open Knowledge on Invasive Species (INVASIVESNET), formed by linking new and existing networks of interested stakeholders. The association developed technical tools and cyber infrastructure for the collection, management and dissemination of data and information on IAS; create an effective communication platform for global stakeholders; and promote coordination and collaboration through international meetings, workshops, education, training and outreach (Lucy *et al.*, 2016).

India's Efforts

Although there is no exclusive legislation or policy in India to deal with the invasive alien species and their eradication so far, The National Biodiversity Action Plan (2008) of the country emphasised the need for regulation of introduction of invasive alien species and their management and it aimed to develop unified national system for regulation of all introductions including their quarantine check, assessment and release, improving management of invasive alien species and restoring the adversely affected ecosystems. Plant Quarantine Order 2003 under Destructive Insects and Pests Act, 1914 has been issued by Directorate of Plant Protection, Quarantine and Storage to prevent introduction of alien insects, fungal or other pest species (http://ppqs.gov.in/). Ministry of Shipping has identified National Institute of Oceanography (NIO) as a lead Research and Development agency for helping address ballast water management issues including port biological baseline survey, ballast water risk assessment and identification of ballast water discharge sites under 'Global Ballast Water Management Programme' and 'Government of India'. National Institute of Oceanography (NIO) is preparing a comprehensive ballast water management plan for major ports during 2010-2016 (http://www.nio.org).

The 12th Five Year Plan (2012-2017) has emphasised the need for a national invasive species monitoring system to track the introduction and spread of invasive species and advised that such a system should be linked to the State Forest Departments, and field staff should be trained to collect information on invasive species. Considering the various ecological impacts of invasive species recently the Ministry Environment, Forest and Climate Change, Government of India has identified eradication/control of Alien invasive species as one of 15 priority areas for undertaking various forestry research in the country and the Ministry is supporting State Forest Department in control and eradication of Forest Invasive Species through centrally sponsored scheme: "Intensification of forest management. The Indian Council of Forest Research and Education, Dehradun India has established 'Forest

Invasive Species Cell' and formulated a All India Coordinated Research Project (AICRP) for management of key Invasive Alien Plant Species with the objectives to establish database on forest invasive species in India, networking and capacity building towards management of invasive species and development of better technology to eradicate invasive species. Although these efforts are appreciable, coordinated and comprehensive efforts are required for effective management of invasive species.

DOCUMENTATION OF IAPS IN THE COUNTRY

Introduction of exotic plants in Indian peninsular region has started in ancient times. About 40% of the species in the Indian flora are alien, of which 25% are invasive (Gupta, 2004; Raghubanshi *et al.*, 2005). As a mega diverse country, India harbors 45,000 wild plant species and about 90,000 animal species in less than 50% geographical region surveyed so far (MoEF, 2008). A recent study has reported the occurrence of 1,599 alien plant species belonging to 841 genera in 161 families in India, and the alien flora thus represents 8.5 % of the total Indian vascular flora (Reshi and Khuroo, 2012). In India, several researchers and organizations (Thakur *et al.*, 1992; Singh *et al.*, 1996; Bahar, 2000; ICFRE, 2005; Soni *et al.*, 2006; Paulsamy *et al.*, 2007; Naithani and Pande, 2009; Kimothi *et al.*, 2010; Srivastava and Singh, 2011; Reshi and Khuroo, 2012, Divakara and Prasad, 2015; Singh *et al.*, 2016) had studied the different aspects of invasive alien plant species. There are several other reports available that provide information on the invasive flora of a particular region/area (Kohli *et al.*, 2006; Khuroo *et al.*, 2007; Negi and Hajra, 2007; Reddy, 2008; Chandra Sekar, 2012; Khuroo *et al.*, 2012). National Biodiversity Authority (NBA) has compiled 53 invasive alien plant species in terrestrial and 7 species in aquatic ecosystems (Sandilyan *et al.*, 2018). India is currently dealing with number of invasive alien plant species such as *Lantana camara* (Murali and Setty.,2001), *Parthenium hysterophorus* (Aneja, 1991; Gunaseelan,1998; Singh and Kaur, 1997; Sankaran *et al.*, 2013), *Mikania micrantha* (Gogoi 2001; Sankaran and Srinivasan, 2001; Lahkar *et al.*,2011), *Prosopis juliflora* (Dayal, 2007; Anoop, 2010; Kaur *et al.*, 2012), *Chromolaena odorata* (Mahajan and Azeez, 2001., Sankaran *et al.*, 2013; Naithani *et al.*, 2017) and so on.

Kimothi *et al.*, (2010) have observed that the terrestrial exotic species like *Cytisus scoparius* L., *Chromolaena odorata* (L.) King & H. Rob., *Eupatorium adenophorum* (Spreng.) King & H. Rob., *Lantana camara* L., *Mikania micrantha* Kunth, *Mimosa invisa* C. Wright, *Parthenium hysterophorus* L. and *Prosopis juliflora* Stuntz DC. and aquatic exotics like *Eichhornia crassipes* (Mart.) Solms and *Pistia stratiotes* L. posing serious threat to the native Flora of India. They also suggested that during the past few decades, India has witnessed negative impact on forest ecosystems posed by various invasive species. Among them, *Lantana camara* (Verbenaceae) is one of the most serious invasive plant species and has colonized large areas of forest in the Himalayan foothills (Shiwalik range), particularly the Dudhwa, Corbett and Rajaji National Parks. It has also invaded the wastelands and forest areas of Western Ghats and other ecosystems especially in peninsular and northeast India (Murali and Setty 2001; Negi *et al.*, 2019). In some of the areas of the park, *Lantana* growth has completely replaced original native forests and palatable grasses, the main food of several species of herbivorous animals (Joshi, 2002; Negi *et al.*, 2019).

Srivastava *et al.*, (2014) worked in Terai landscape of North-eastern Uttar Pradesh with the objective of documentation of IAS in this region. Subsequently they documented a total of 149 species of IAS belonging to 100 genera under 41 families. The alien species amounted to 13.1% of 1135 wild terrestrial plant species of the region.

An exhaustive floristic survey was carried out by Nayak and Bihari (2015) in the Dhenkanal district of Odisha state to assess the diversity, nativity and uses of IAS. The study observed that a total of 131 species with 97 genera and 39 different families were invasive alien plants. These included most invasive species, such as *Chromolaena odorata, Lantana camara, Hyptis suaveolens, Ageratum conyzoides, Parthenium hysterophorus, Eichhornia crassipes, Alternanthera philoxeroides* and others.

Studies carried out in Southern Eastern Ghats lists out around 47 invasive alien plants, of which most of them were herbaceous in nature, about six of them was liana such as *Basella alba, Ipomoea asarifolia, Rubus ellipticus, Solanum* *seaforthianum, Rubus niveus,* and *Lantana camara* (Parthasarathy *et al.*, 2011). Some humid grasslands of North-eastern India too are invaded by few invasive species such as *Ageratum conyzoides, Chromolaena odorata, Imperata cylindrica, Mikania micrantha* and these species are a cause of concern in diverting grasslands into savannas (Uma Shankar *et al.*, 1991). Shah and Reshi (2012) reported that the invasive macrophytes which are primarily free-floating in fresh water ecosystems especially in the ponds, streams inside the forest are known to create severe threat the water bodies by decreasing the depth. These invasive aquatic plants impact the structure and function of freshwater ecosystems.

Though various attempts have been made to document the invasive species of the country, most of the studies are conducted at local scale, often species specific and employed numerous methodologies and approaches to document the invasive alien plant species. Further few studies have prepared a comprehensive list of IAPs of India but as invasion of species in different parts of India is proceeding with significant pace, an updated inventory document of invasive alien plant species (IAS) is not yet prepared. Moreover, a perusal of the literature also revealed that various authors have quoted both accepted name and synonym of a species as separate species and in some cases naturalised and native species are listed as invasive species. In this scenario, the present document attempted to identify and document the alien invasive plant species in India based on invasive attributes of the plant such as invasiveness, impacts and range extension. The documented lists of invasive species are given in Annexure – 1 and some of the images of the IAPS are given in Plate 1 to 3.

A National database containing information such as botanical name, vernacular name, habit of growth, family, origin and reference studies which have reported the particular plant species as invasive alien plant species need to be developed for sharing of information on IAPS. The profile schema, which has been developed to facilitate sharing of information among different databases through the use of common or core data elements are available through the Global Invasive Species Information Network. This profile schema may be used as template for the proposed National database on IAPS to increase awareness about invasive alien species and to facilitate effective prevention and management activities (ISSG 2015).

CONCLUSION

As a part of achieving the Aichi target 9 and also to follow The National Biodiversity Action Plan (2008), we need not only to document the IAPS but also to identify pathways of invasive species and prioritize IAPS for effective control or eradication to prevent further introductions and establishment.

The spread of IAPS over a broad region can be systematically monitored to assess its current cover to frame management strategies for IAPS. Ground surveys have been used for monitoring invasive alien species and the extent of occurrence of IAPS. Apart from the traditional field survey, remote sensing techniques which are an important tool for large-scale ecological studies can be used as it is cost as well as time effective. Based on the satellite images, the spatial extent of prioritized IAPS can be mapped which will be highly useful for effective management of prioritized IAPS.

To help and better prioritize management strategies, Species Distribution Models (SDMs) may be used to predict the potential invasive range of prioritized IAPS. This method helps to assess present spread of IAPs in any region with help of several remote sensing applications. Further, the baseline distribution maps can also be used to assess the impact of climate change on the distribution of invasive species.

A web-based mapping system for documenting invasive species distribution which combines data from other databases and organizations as well as volunteer observations using mobile Applications to create a national network of invasive species distribution data may be designed so that it can be shared with scientists, researchers, land owners, educators, conservationists, ecologists, farmers, foresters and beyond.

Eradication programmes have been attempted in many parts of the world, using manual, mechanical, chemical and biological techniques, but with only limited success to date (Shackleton *et al.*, 2014). There is also a need for research to better predict trends such as future densities, extent and impacts which is particularly important when it comes down to developing strategic responses. There is no baseline information for predicting the future trends and effects of management interventions. Further, the economic exploitation of invasive species as a means of harnessing their economic potentials for meeting basic human needs and at the same time control its spread and possibly eradicate them is also need to be further studied. Therefore, there is an urgent need to assess IAPS and develop appropriate strategies for their management and control which will definitely be helpful in ensuring the ecological security of the country.

SOME OF INVASIVE ALIEN PLANT SPECIES OF THE COUNTRY

Ageratina adenophora (Spreng.) R.M.King & H.Rob

Ageratum houstonianum Mill.

Cytisus scoparius (L.) Link

Ulex europaeus L.

Ipomoea carnea Jacq.

Pontederia crassipes Mart.

(Photo credit: Dr. S.P.Subramani, IFGTB, Coimbatore)

ADDITIONAL INVASIVE ALIEN PLANT SPECIES OF THE COUNTRY

Antigonon leptopus Hook. & Arn.

Cestrum aurantiacum Lindl.

Lantana camara L.

Mikania micrantha Kunth

Parthenium hysterophorus L.

Tagetes minuta L.

(Photo credit: Dr. A. Rajasekaran, IFGTB, Coimbatore)

SELECTED INVASIVE ALIEN TREES AND SHRUB SPECIES

Acacia mearnsii De Wild.

Leucaena leucocephala (Lam.) de Wit

Muntingia calabura L..

Prosopis juliflora (Sw.) DC

Senna spectabilis (DC.) Irwin & Barneby

Solanum mauritianum Scop.

(Photo credit: Dr. A. Rajasekaran, IFGTB, Coimbatore)

REFERENCES

Aneja, K.R. (1991). Biotechnology for the production and enhancement of mycoherbicide potential. In: From Ethnomycology to Fungal Biotechnology Plenum, London, UK, 91-114.

Anoop, K.R. (2010). Progress of *Prosopis juliflora* eradication work in Keoladeo National Park. Report, Rajasthan Forest Department, Rajasthan.

Bahar, N. (2000). Studies on occurrence and control of *Parthenium hysterophorus* Linn. Indian Forester, 126:903-904.

Bais, H.P., Vepachedu, R., Gilroy, S., Callaway, R.M. and Vivanco, J.M. (2003). Allelopathy and exotic plants: from genes to invasion. Science, 301: 1377-1380.

Baker, H.G. (1974). The evolution of weeds. Annual Review of Ecology and Systematics, 5: 1-24.

Bhatt, J.R., Singh, J.S., Singh, S.P., Tripathi, R.S. and Kohli, R.K. (Ed.), (2011). Invasive Alien Plants: An ecological appraisal for the Indian Sub Continent (Vol. 1), CABI, UK.

Blossey, B. and Notzold, R. (1995). Evolution of increased competitive ability in invasive non-indigenous plants: A hypothesis. Journal of Ecology, 83(5): 887-889.

Callaway, R. M. and Ridenour, W. M. (2004). Novel weapons: invasive success and the evolution of increased competitive ability. Frontiers in Ecology and the Environment, 2(8): 436-443.

Callaway, R.M. and Aschehoug, E.T. (2000). Invasive plants versus their new and old neighbours: a mechanism for exotic invasion. Science, 290: 521-523.

CBD. (2002). COP 6 Decision V/23. Alien species that threaten ecosystems, habitats or species. Interim guiding principles for the prevention, introduction and mitigation of impacts of alien species. Sixth Ordinary Meeting of the Conference of the Parties to the Convention on Biological Diversity, 7–19 April 2002, The Hague, Netherlands, https://www.cbd.int/decision/cop/?id=7197.

CBD. (2010). Aichi Biodiversity Target 9 of the Strategic Plan for Biodiversity 2011–2020. Tenth meeting of the Conference of the Parties to the Convention on Biological Diversity, 18–29 October 2010, Nagoya, Aichi Prefecture, Japan, https://www.cbd.int/sp/targets/rationale/target-9/.

CBD. (2016). Convention on Biological Diversity, Programme of Work on Invasive Alien Species, https://www.cbd.int/invasive/.

Chandra Sekar, K. (2012). Invasive alien plants of Indian Himalayan Region - Diversity and Implication. American Journal of Plant Science, 3: 177-184.

Darwin, C. (1859). On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life. John Murray, London.

Davis, M. A., Grime, J. P., and Thompson, K. (2000). Fluctuating resources in plant communities: a general theory of invasibility. Journal of Ecology, 88(3): 528-534.

Dayal, V. (2007). Social diversity and ecological complexity: how an invasive tree could affect diverse agents in the land of the tiger. Environment and Development Economics, 12:553-571.

di Castri, F. (1989). History of biological invasions with special emphasis on the old world. Biological Invasions: a Global Perspective (J.A. Drake, H.A. Mooney, F. di Castri, R.H. Groves, F.J. Kruger, M. Rejmánek and M. Williamson, Eds.), pp. 1–30. John Wiley & Sons, New York.

Divakara, B. N. and Prasad, S. (2015). Ethnomedicinal Importance of Invasive Alien Flora of Latehar and Hazaribagh Districts: Jharkhand, Indian Forester, 141(11):1172-1175.

Elton, C.S. (1958). The Ecology of Invasions by Animals and Plants. Metheun, London.

Global Invasive Species Database (GISD), (2010). Invasive Species Specialist Group of the IUCN.

Gogoi, A.K.(2001). Status of *Mikania micrantha* infestation in Northeastern India: management options and future research thrust. In: Alien weeds in moist tropical zones: banes and benefits (Sankaran, K.V., Murphy, S.T. and Evans, H.C., Eds.), KFRI/CABI Bioscience, Kerala/Ascot, pp 77-79.

Gray, A. (1879). The predominance and pertinacity of weeds. American Journal of Science and Arts, 118, 161-167.

Gunaseelan, N.V. (1998). Impact of anaerobic digestion on inhibition potential of *Parthenium hysterophorus* solids. Biomass Bioenergy, 14:179-184.

Gupta, K. (2004) National Bureau of Plant Genetic Resources, New Delhi, India.

Hierro, J. L., Maron, J.L. and Callaway, R. M. (2005). A biogeographical approach to plant invasions: the importance of studying exotics in their introduced and native range. Journal of Ecology, 93, 5-15.

ICFRE (2005). Forest Invasive Species. Dehra Dun: Indian Council of Forestry research and Education.

Invasive Species Specialist Group (ISSG 2015). The Global Invasive Species Database (GISD),Version 2015.1.

IPBES. (2016). Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services, Work Programme Deliverable 3(b)(ii): Thematic assessment on invasive alien species and their control. http://www.ipbes.net/work-programme/invasivealien-species

IUCN. (2017). Consultation document. IUCN standard classification of the impact of invasive alien taxa. Version 1 May 2017.

Joshi, A.P. (2002). Lantana. Himalayan Environment Studies and Conservation Organization, Vigynanprasth, Dehradun.

Kaur, R., Gonzales, W.L., Llambi, L.D., Soriano, P.J., Callaway. R.M., Rout, M.E. and Gallaher, T.J. (2012).Community impacts of *Prosopis juliflora* invasion: biogeographic and congeneric comparisons, PLoS ONE, 7:e44966.

Khuroo, A.A., Rashid, I., Reshi, Z., Dar, G.H. and Wafai, B.A. (2007). The alien flora of Kashmir Himalaya, Biological Invasions, 9:269-292.

Khuroo, A.A., Reshi, Z.A., Malik, A.H., Weber, E., Rashid, I. and Dar, G.H. (2012). Alien flora of India: taxonomic composition, invasion status and biogeographic affiliations. Biological Invasions, 14:99-113.

Kimothi, M.M., Anitha, D., Vasistha, H.B., Soni, P., and Chandola, S.K. (2010). Remote sensing to map the invasive weed, *Lantana camara* in forests, Tropical Ecology, 51(1): 67-74.

Kohli, R.K., Batish, D.R., Singh, H.P. and Dogra, K.S. (2006). Status, invasiveness and environmental threats of three tropical American invasive weeds *(Parthenium hysterophorus* L.*, Ageratum conyzoides* L.*, Lantana camara* L.*)* in India. Biological Invasions, 8:1501-1510.

Lahkar, B.P., Talukdar, B.K. and Sarma, P. (2011). Invasive species in grassland habitat: an ecological threat to the greater one-horned rhino *(Rhinoceros unicornis)*, 49:33-39.

Lee, C.E. (2002). Evolutionary genetics of invasive species. Trends in Ecology and Evolution, 17: 386-391.

Lonsdale, W.M. (1999). Global patterns of plant invasions and the concept of invasibility. Ecology, 80: 1522-1536.

Lucy, F. E., Roy, H., Simpson, A., Carlton, J.T., Hanson, J. M., Magellan, K., Campbell, M. L., Costello, M.J., Pagad, S., Hewitt, C.L., McDonald, J., Cassey, P., Thomaz, S.M., Katsanevakis, S., Zenetos, A., Tricarico, E., Boggero, A., Groom, Q.J., Adriaens, T., Vanderhoeven, S., Torchin, M., Hufbauer, R., Fuller, P., Carman, M. R., Conn, D. B., Vitule, J.R.S., Clode, J.C., Galil, B. S., Ojaveer, H., Bailey, S.A., Therriault, T.W., Claudi, R., Gazda, A., Dick, J.T.A., Caffrey, J., Witt, A., Kenis, M., Lehtiniemi, M., Helmisaari, H. and Panov, V.E. (2016). INVASIVESNET towards an International Association for Open Knowledge on Invasive Alien Species. Management of Biological Invasions, 7 (2): 131-139.

MacArthur, R.H. (1970). Species packing and competitive equilibrium for many species. Theoretical Population Biology, 1: 1-11.

MacArthur, R.H. (1972). Geographical Ecology: Patterns in the Distribution of Species. Harper & Row, New York.

Mahajan, M., Azeez, P.A. (2001). Distribution of selected exotic weeds in Nilgiri Biosphere Reserve. In: Alien weeds in moist tropical zones: banes and benefits (Sankaran, K.V., Murphy, S.T. and Evans, H,C, (Eds.), KFRI, India & CABI Bioscience, UK, pp 46-55.

Meyerson, L.A., Mooney, H.A., (2007). Invasive alien species in an era of globalization. Frontiers in Ecology and the Environment, 5 (4): 199-208.

Ministry of Environment and Forests (MoEF).(2008). National Biodiversity Action Plan. http://envfor.nic.in/division/csurv/Approved NBAP.pdf.

Murali, K.S. and Setty S. R. (2001). Effects of weeds *Lantana camara* and *Chromolaena odorata* growth on the species diversity, regeneration and stem density of tree and shrub layer in BRT sanctuary. Current Science, 80:675-678.

Naithani, H.B., Shah, R. and Rasaily, S.S. (2017). Study on qualitative and quantitative survey of invasive species in Dehradun district. Published by Uttarakhand Biodiversity Board, 108, Phase- II, Vasant Vihar, Dehradun.

Naithani, S., and Pande, P.K. (2009). Evaluation of *Lantana camara* Linn. stem for pulp and paper making. Indian Forester, 135 (8): 1081-1087.

Nayak, S.K., and Bihari, S.K. (2015). Uses and Origin of Invasive Alien Plants in Dhenkanal district of Odisha, India. International Research Journal of Biological Sciences, 4(2): 21-27.

Negi, P.S. and Hajra, P.K. (2007). Alien flora of Doon Valley, Northwest Himalaya. Current Science, 92.

Negi, G.C.S., Subrat Sharma, Subash C.R. Vishvakarma, Sher S. Samant, Rakesh K. Maikhuri, Ram C. Prasad, Lok M. S. Palni (2019). Ecology and Use of *Lantana camara* in India, Bot. Rev. 85: 109-130.

Parthasarathy, N., Pragasan, L. A. and Muthumperumal, C. (2011). Invasive alien plants in tropical forests of the south-eastern Ghats, India: Invasive alien plants an ecological appraisal for the Indian subcontinent (Bhatt, J. R., Singh, J. S., Singh, S. P., Tripathi, R. S., and Kohli, R. K., Eds.), Cabi, pp. 162-173.

Paulsamy, S. , Padmavathy, S. , Pannerselvam, T., S. , Senthilkumar, D. (2007). Population size of a weed, *Lantana camara* L. in the understorey of teak forests of Anaimalais, Western Ghats as influenced by upper canopy cover. Indian Forester, 133(2): 165-170.

Raghubanshi, A. S. , Rai, L.C., Gaur, J.P., and Singh, J. S. (2005). Invasive alien species and biodiversity in India, Current science, 88(4):539-540.

Reddy, C.S. (2008). Catalogue of invasive alien flora of India. Life Science Journal, 5: 84-89.

Reddy, C.S., Bagyanarayana, G., Reddy, K.N., Vatsavaya, S.R. (2008). Invasive alien flora of India. National biological information infrastructure, US Geological Survey, USA.

Sandilyan, S., Meenakumari, B., Babu, C.R. and Rupam Mandal (2018). Invasive alien species of India, National Biodiversity Authority, Chennai.

Sankaran, K.V. and Srinivasan, M.A. (2001). Status of Mikania infestation in the Western Ghats. In: Alien weeds in moist tropical zones: banes and benefits (Sankaran, K.V., Murphy, S.T. and Evans, H.C. Eds.), KFRI/CABI Bioscience, Kerala/Ascot, pp 67-76.

Sankaran, K.V., Suresh, T.A. and Sanjeev, T.V. (2013). Handbook on Invasive plants of Kerala. By Kerala biodiversity Board.

Shackleton, R.T, Le Maitre, D.C, Pasiecznik, N.M. and Richardson, D.M. (2014). Prosopis: A global assessment of the biogeography, benefits, impacts and management of one of the world's worst woody invasive plant taxa. AoB Plants 6, plu027.

Shah, M.A. and Reshi, Z.A. (2011). Invasion by alien macrophytes in freshwater ecosystems of India. In: Invasive alien plants an ecological appraisal for the Indian subcontinent (Bhatt, J. R., Singh, J. S., Singh, S. P., Tripathi, R. S., and Kohli, R. K. Eds.), Cabi, pp.199-213.

Singh, A. G., and Sharma, A. (2014). Documentation of invasive alien plants species of Rupandehi district, Western Nepal, International Journal of Applied Sciences and Biotechnology, 2(2): 168-175.

Singh, C:M, N; MvAngiras and S; Kumar. (1996). Weed Management. MD Publications, New Delhi.

Singh, K. and Kaur, K. (1997). Parthenium menace in Jammu and Kashmir and its possible control measures. 16-19. In: First International Conference on Parthenium Management held at Dharwad (Karnataka) (M. Mahadevappa, and V.C. Patil, Eds.), 2: 16-19.

Soni, P.L., Naithani, S., Gupta, P.K., Bhatt, A. and Khullar, R. (2006). Utilization of economic potential of *Lantana camara.* Indian Forester, 132 (12): 1625-1630.

Srivastava, S., Dvivedi, A. and Shukla, R.P. (2014). Invasive alien species of terrestrial vegetation of North-Eastern Uttar Pradesh. International Journal of Forestry Research, 1-9.

Stockwell, D. and Peters, D. (1999). The GARP modelling system: problems and solutions to automated spatial prediction. International Journal of Geographical Information Science, 13:143-158.

Thakur, M.L., Anmad, A. and Thakur, R.K. (1992). Lantana weed *Lantana camara* var. *aculeata* Linn and its possible management through natural insect-pests in India. Indian Forester, 118(7): 466-488.

Trullas, C. S. and Garcia, R.A. (2017). Impacts of invasive plants on animal diversity in South Africa : a synthesis.

Uma Shankar, Tripathi, R. S. and Pandey, H.N. (1991). Structure and seasonal dynamics of humid tropical grasslands in Meghalaya, India. Journal of Vegetation Science, 2:711-714.

Vilà, M. and Weiner, J. (2004). Are invasive plant species better competitors than native plant species? - Evidence from pair-wise experiments. Oikos. 105: 229 - 238.

Williams, J.R. (1954). The biological control of weeds. Report of the sixth commonwealth entomological congress, London, United Kingdom, 95-98.

Williamson, M. (1996). Biological Invasions. Chapman and Hall, London.

Websites:

http://ppqs.gov.in/

http://www.issg.org/pdf/publications/GISP/GISP_TrainingCourseMaterials/Management/ManaginginvasivesModule1.pdf

http://www.nio.org

2 REMOTE SENSING FOR MAPPING INVASIVE ALIEN PLANTS: OPPORTUNITIES AND CHALLENGES

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INTRODUCTION

The array of satellite sensors deployed for Earth observation has diversified and increased rapidly in recent decades. Satellite-based remote sensing enables the synoptic, multi-temporal and systematic repeated observation at an economical cost. Remote sensing as defined by Lillesand et al., (2014) refers to the "science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation". Remote sensing data and products for various Earth observation are now freely available from multiple sources which include USA based National Aeronautics and Space Administration (NASA) Earth Data products (https://earthdata.nasa.gov/), US Geological Survey (https://earthexplorer.usgs.gov/), and National Oceanic and Atmospheric Administration (NOAA) (https://www.nesdis.noaa.gov/) data sets; products made available by European Space Agency (https://earth.esa.int); and the open data archive Geo-platform of Indian Space Research Organisation (ISRO) through "Bhuvan" (http://bhuvan.nrsc.gov.in). The era of extensive use of satellite-based remote sensing began in 1972 with the launch of first Landsat satellite by USA (Cohen and Goward, 2004), offering continuous coverage of the Earth. Since then, in situ small plot, ocular observations have been supported by remotely sensed observations varying from local, regional to global coverage. The developing capabilities for monitoring Earth features and phenomenon through remote sensing at relatively higher spatial, spectral and temporal resolution have benefitted researchers, planners and managers to fulfill numerous requirements.

Multiple data products from different satellite sensors have widely been used for monitoring and mapping of natural resources (Boyd and Foody, 2011; Cohen and Goward, 2004), conservation and management of habitat of important species (Corbane *et al.*, 2015; Turner *et al.*, 2003), weather and climate related phenomenon (King *et al.*, 1992). Indeed, the application continues to grow covering various disciplines of science. The potential for the application of remote sensing has emerged as a prominent research topic (Corbane *et al.*, 2015). Today a broad variety of remote sensing data and products are available that can be used for multiple purposes. Use of these products in mapping the spatial pattern and extent of vegetation has successfully been tested and applied extensively (Atzberger and Eilers, 2011; Carreiras *et al.*, 2006; FSI, 2011; Han *et al.*, 2004; IIRS, 2002; ISFR, 2017). At the same time, there has been a growing interest of researchers in mapping the invasive alien plant species using remote sensing. Detection and mapping of invasive plants supported by remote sensing techniques have emerged as a promising alternative to field surveys (Lass *et al.*, 2005). Early detection of invasion reduces the cost of control to eradicate invasion and manage lands which are now assisted with the advent of remote sensing technologies. The major focus is shifting towards the development of low-cost technologies and improving capabilities to retrieve meaningful information while applying new computational tools and algorithm. Apart from having applicability in the field of invasive plants mapping, the use of remote sensing is growing for its wider use in all other domains of environmental monitoring. The separation of objects having a distinctive spectral signature is easier compared to the objects with close signature, however, there has been successful attempt when very similar categories are to be distinguished, e.g., the distinction of native and invasive species. Distinction abilities have improved because of improvement in sensor capabilities and classification algorithm. However, compared to the mapping of dominant big canopy trees, the mapping of lesser canopy plants or the plants growing under the canopy - such as invasive species may not be easy. Nevertheless, various successful efforts have been made in this direction with a variety of approaches that integrate the application of remote sensing. We discuss here the various approaches together with the opportunities and challenges of mapping invasive alien plant species using remote sensing.

REMOTE SENSING: AN OVERVIEW

Remote sensing involves a multitude of tools, techniques and scientific disciplines involving the use of the computer, software, optics, photography, spectroscopy, satellite and aerial vehicles, telecommunication, etc. All of these combine together to represent remote sensing. It may involve the use of aircraft, Unmanned Aerial Vehicles (UAVs), spacecraft/satellites where specific sensors are mounted for acquiring the Earth observation remotely. The application of remote sensing for mapping large area grew only after the use of aerial photography through airborne sensors for mapping inaccessible areas. Aerial mapping evolved in due course of time with the use of space-based sensors installed on satellites. These sensors detect variations in reflectance wavelength of features being mapped. The mapping differs in spatial and spectral resolution. Spatial resolution refers to the size of the pixel, while the spectral resolution refers to the number of wavelength ranges for which reflectance energy is captured. A higher spatial resolution has the more capability to segregate two closely placed objects represented by smaller size pixels, whereas, higher spectral resolution usage number of wavelength bands for capturing reflected energy with better chances of segregation of objects. Remote sensing can involve the use of either an active or passive sensor termed as active and passive remote sensing, respectively.

An "active sensor" has their own source of energy (such as Radio Detection and Ranging, RADAR, Light Detection and Ranging, LiDAR) where the "passive sensor" do not have their own source of energy and depends upon the external source of illumination such as Sun. Different objects by the virtue of their composition and nature reflect different amount of energy in different wavelengths of the electromagnetic spectrum, giving a unique pattern of reflectance or signature commonly referred as the "spectral signature". The various common terms used much frequently in remote sensing has been presented in Table 1.

Table 1.
Common terms related to remote sensing and their explanation

Term	Explanation
Energy source	The source of energy that illuminates or provides electromagnetic energy to the target of interest. In passive remote sensing, the source is Sun while in active remote sensing sensors have their own source of energy.
Hyperspectral remote sensing	Remote sensing producing images having several spectral narrow contiguous bands (generally >100) with no wavelength omissions. These images are referred as "Hyperspectral images". Hyperspectral images have relatively narrow bandwidths in the range of 0.01-0.05 µm compared to multispectral images which have bandwidth usually in the range of 0.07-0.4 µm. It is a cubical representation of data in which X-Y plane represents surface sensed, whereas, Z direction contains multiple spectral information.
Microwave remote sensing	Remote sensing utilising wavelengths in the range of 1 cm to 1 m (commonly referred as microwaves). Compared to the visible and infrared ranges, these have greater wavelength

	and can penetrate clouds. This helps to acquire information for the cloud covered regions where other wavelengths are not much successful in acquiring information.
Multispectral image	Image having a reflectance value of a particular area in multiple wavelength bands represented by 5-10 bands having bandwidth in the range of 0.07-0.40 µm.
Near-infrared (NIR) wavelength	Wavelengths range between 0.7 to = 1 µm. This region is of particular interest for segregation and mapping vegetation as the reflectance value in this range is maximum for the vegetation compared to other Earth surface features.
Normalized Difference Vegetation Index (NDVI)	An index used for highlighting vegetation of an area where the difference in the reflectance value of near infrared (NIR) and red band (R) is utilized. NDVI is represented by a ratio of (NIR-R)/(NIR+R). NDVI ranges between -1 to +1, where the value closer to +1 suggest a high possibility of having vegetation whereas values close to -1 suggest for water. The range of NDVI for vegetation and water relates to their reflectance behaviour in NIR and R band, where vegetation reflects much in NIR while there is absorption in the red and blue band; whereas, for water reflectance value in NIR is almost zero while there is little reflectance in the red and blue band.
Optical remote sensing	Remote sensing utilising the wavelength ranges of the visible (0.4 to 0.8 µm), near infrared (NIR), shortwave infrared (SWIR) or the thermal infrared (TIR, 10 to 15 µm). Much often just the wavelength ranges of 0.25 to 3 µm is used in which significant energy of solar radiation is reflected back from the Earth while the other ranges suffer scattering and absorption thus less useful.
Panchromatic image	Images sensed in a broader wavelength range and unlike multispectral sensors which provides multiple images in multiple wavelengths ranges, panchromatic sensors provide just one image covering wide wavelength range. A panchromatic image sensed in the visible range (0.4-0.7 µm) resembles a “black and white image” taken from space as the spectral information or “colour” is lost, being a single broad range.
Passive and Active remote sensing	Passive remote sensing involves the use of passive sensors detecting Sun’s reflected energy from the Earth as they do not have their own source of energy, whereas, “active sensors” detect their own reflected back energy from the source as they have their own source of energy.
Phenology	“The study of recurring plant and animal life cycle stages, especially their timing and relationships with weather and climate” (Schwartz, 2003). Different phenological events such as leaf formation, leaf maturation, leaf fall, bud formation, flowering, fruiting, seed-setting (formation of seeds within fruit), seed dispersal, etc. support identification and separation of invasive plants and can be captured using remote sensing.

Pixel	Representation of the Earth surface as individual picture elements in a digital image. Pixels (also referred as cells) are arranged in an image as two dimensional array and it is the smallest unit of measurement in an image. It is represented as square unit area sensed by a sensor into length and width, however, the expression is generally a length of one square side, e.g. 30 m pixel represents 30 x 30 m.
Reflectance	Amount of energy reflected from the object out of the total energy incident upon it. It is generally expressed as the percentage value of reflected energy out of total incident energy.
Remote sensing	The science and art of obtaining information about the Earth's surface without actually being in contact with it. On the basis of the platform where the sensors are installed this is grouped into aerial and satellite remote sensing.
Short wave infrared (SWIR) band	Wavelengths range between 1 to 2.5 m. The first initial range typically consisting of 1.5-1.7 m is referred as SWIR 1, whereas, the next range of 2.0-2.5 m is referred as SWIR 2. This is also referred as water absorption band which shows a drop in reflectance value where there is water or moisture content. A low reflectance in these bands suggests for vegetation or surface having relatively good water content compared to those where we receive high reflectance.
Spatial resolution	Spatial resolution refers to the detection capability of the sensor for segregating two closely placed objects. It is the smallest area scanned by a sensor for which the reflectance value is stored. It represents the size of the pixel sensed by a sensor.
Spectral band	A range of wavelength in which sensors capture reflected energy. E.g. 0.4-0.5 m, 0.5-0.6 m and 0.6-0.7 µm represents blue, green and red bands, respectively.
Spectral signature	The amount of energy reflected by different land features in different wavelength ranges differ. The reflectance pattern of different wavelengths for a feature class is referred as “spectral signature” of that class or object. The per cent reflectance of various land classes (reflectance) represented by vegetation, water, soil, etc. varies for different wavelength ranges. This helps to segregate and classify the objects on the basis of reflectance behaviour into various groups/classes. Similar objects have similar spectral signature while two distinct class of object will have a very different spectral signature.
Swath	The area sensed and imaged by a sensor in one scene is called the “Swath” of the sensor. At a given time, a sensor focuses on a certain portion of the Earth which is captured in a scene/image equivalent to the swath of the sensor.
Temporal resolution	The time period after which a sensor/satellite gain visits the same area for the acquisition of the image. It is also referred as the “repeativity” or the “revisit” period of the sensors/satellites.

REMOTE SENSING FOR MAPPING INVASION AND OTHER CLASSES: OPPORTUNITIES

Mapping of invasion or other land cover classes were dependent upon the field based survey prior to the advent of remote sensing technologies. The field based surveys provided limited information and understanding about the complex terrains while they are labour intensive and time consuming (Calviño-Cancela *et al.*, 2014). Further, the field based survey alone has the biases of the surveyors in the form of surveying just the accessible area, misclassifying species, reluctance for having temporal data, etc. Remote sensing provides additional support as well as alternative to the field surveys. It provides information for inaccessible terrains reasonably for a larger extent with lesser time and effort. Compared to the very early stages of mapping which was totally field based ocular observations, now the remotely sensed data products provide added advantage. Mapping is possible for wider areas ranging from local, regional to global extent at multi-temporal resolution. Remote sensing based observations are available at relatively reduced effort and time and in an economical way. However, remote sensing needs to be applied always in combination with the field based surveys as both methods complement each other.

Looking at the need for supplementing field surveys and requirement of effective systematic monitoring, remote sensing emerged as an effective tool. The modern tools of remote sensing together with computer assisted information system in the form of Geographical Information System (GIS) have helped researchers in various domains. Remote sensing assisted by GIS provides the opportunity for in-depth study of complex multi-dimensional ecological processes and pattern. Remote sensing is effective in mapping plant distribution including the spread of invasive plants with certain limitations. However, recent advancements in remote sensing endeavour to overcome the limitations and considerable success has been achieved in mapping invasion at the species level.

The tools of remote sensing and GIS are used extensively for mapping invasive plants and other vegetation. Various data products acquired through remote sensing are an integral part of this mapping exercise. There has been continuous growth in the development of sophisticated sensors for acquiring necessary information remotely. Today, a number of remotely sensed data sets are available (Table 2) that include multispectral and hyperspectral data with multi-temporal coverage appropriate for invasion mapping. Multiple space based agencies operating in different countries are providing regional to global coverage of data sets appropriate for mapping. A brief description of the type of data and their sources that could be utilized for mapping invasion and other classes is depicted in Table 2.

Several remote sensing tools and methodologies are available that can be used for the diverse habitats to locate and map the invasive plants. This encompasses the use of ground, aerial as well as satellite based remote sensing. The adopted methods vary from simple approach of supervised classification of images to complex approaches using multi-sensor data and combination of techniques. Separation and classification of objects become easier when the target of detection has a contrast in reflectance with respect to the background. The detection of invasive species may be done easily when the drying season of either of the species differs. Different drying season of species provides an opportunity to capture the high reflectance from the greener parts of the vegetation in the NIR band of various satellite imageries (Table 2). The selection of appropriate imagery for the detection and mapping of invasive plants depend on the spatial and spectral resolution, coverage area of the sensors, cost of the images and the availability of the image corresponding to the appropriate time period of detection and mapping. Consideration of images on the basis of spatial resolution is important as it determines the detection capacity in terms of spatial closeness and the scale of the study. The images with finer spatial resolution have better classification capabilities with enhanced accuracy compared to the coarser images.

The capacity of a sensor to detect a plant is determined by the interaction of different wavelength with the plants which determines the spectral signature. Spectral signatures are dependent upon the structure and composition of the leaves and other vegetative parts. A combination of leaf biochemical properties such as water and nitrogen concentration determines the spectral signature (Asner *et al.*, 2008). Canopy structure, arrangement of leaves and branches, specific leaf area (leaf area per unit leaf mass), leaf area index, and the overall architecture of the tree determines the spectral signature and thus separation capabilities of the sensors. Moderate spatial resolution images such as Landsat or LISS are only effective to detect species in large conglomeration forming large stands. The application of remote sensing to detect invasive plants using multispectral imagery would be possible if the species forms dense stands with distinct spectral signatures (Cuneo *et al.*, 2009). Moreover, high resolution images such as Quickbird or Worldview-2 are better suited for mapping invasive plants (Bradley, 2014). Finer spatial resolution can detect individual plants more easily. When the detection is limited by the spatial resolution, higher spectral resolution provides an opportunity to detect the species. Low spatial and high spectral resolution imagery is more suited for mapping invasive plants forming monotypic stands, whereas high spatial and high spectral images are more suited for mapping heterogeneous community with a scattered population (He *et al.*, 2011). Spatial resolution determines the accuracy and precision of detection, and as spatial resolution increases so does accuracy (Shouse *et al.*, 2012). High spectral resolution images are taken by Hyperspectral sensors often in hundreds of spectral bands covering visible, infrared and short-wave infrared wavelengths (Bradley, 2014). Hyperspectral sensors have the better capability in detecting invasive plants and are most commonly used for this purpose (He *et al.*, 2011; Huang and Asner, 2009), but this is limited by the non-availability of freely accessible data and the spectral libraries of the individual species. At the same time, the choice of remote sensing approach is dependent on the tradeoff along the axis of temporal, spatial and spectral resolution (Bradley, 2014). The application of remote sensing tools also provides an opportunity to detect species below the canopy of other dominant species. The LiDAR has been used for detecting sub canopy invasion in conjunction with other sensors (Huang and Asner, 2009). LiDAR allows three-dimension structure mapping of invasive plants.

Mapping of the invasive species can also be done by establishing relationship between the occurrence of the species and the predictor variables that guide the establishment of the species (Padalia and Bahuguna, 2017; Srivastava *et al.*, 2018). Spatial modelling for mapping invasion demands prior knowledge and expert opinion about the kind of relationship between the occurrence of the species and the appropriate predictor variables suitable for the modelling. Successful modelling efforts necessitate extensive data to feed as predictor variables which can be acquired through remote sensing. Use of remotely sensed data improves data collection efficiency and the accuracy of predictive spatial models (Cohen and Goward, 2004).

Species Distribution Models (SDMs), based on niche-based concept are now used extensively for mapping invasive plants and the probable risks of invasion (Adhikari *et al.,* 2015; Choudhury *et al.*, 2016; Padalia *et al.*, 2014, 2015; Padalia and Bahuguna, 2017; Panda *et al.,* 2018). Niche-based models have predictive power to map the potential sites where the invasion is likely to happen. This helps managers to take preventive action well in advance to restrict the invasion. However, there is a dearth of publication in the Indian context where extensive mapping for the invasive plants has been done using remote sensing. Most of the studies have been done targeting single species with limited testing of available modelling tools. Application of MaxEnt model (Phillips *et al.*, 2006) in particular have been done extensively compared to the other approaches. Remote sensing fulfils the data requirement of models for its testing and application to invasion mapping. Furthermore, remote sensing based observations help to map the pathways and routes of spread of invasion.

The above discussed facts illustrate that there is ample scope and opportunity while applying remote sensing directly or indirectly for mapping invasive plants with certain limitations which has been discussed ahead.

VARIOUS REMOTE SENSING BASED APPROACHES FOR MAPPING INVASIVE PLANTS

Remote sensing is successful in mapping invasive and other plants when the target is distinctive from the surrounding (Huang and Asner, 2009). The application of remote sensing coupled with GIS and modelling has resulted in multiple methods and tools that can be applied for mapping invasion (Evangelista *et al.*, 2009). The application often relies on the classification of the images captured by various sensors (Table 2). The classification techniques may include hard classifiers such as the maximum likelihood, parallelpiped, Centroid k means, ISODATA and the artificial neural network, and the use of soft classifiers such as Bayesian, fuzzy, linear mixture modelling and spectral mixture analysis. In hard classification techniques a pixel is assigned one and only one category of the object class (e.g. Forest, Agriculture, Water etc. are the object classes), while in soft classification one pixel doesn't belong to one class where the membership of the pixels is assigned to varying levels of association of pixel with different classes.

Table 2.
Brief account of remote sensing data and their sources usable for mapping invasive plants

Sensor	Swath width	Spatial resolution	Period of availability	Temporal resolution	Data sources
Multispectral Images (Freely available)					
ASTER	60 km	15/30/90 m	2000-now	1 day	[1]https://lpdaac.usgs.gov/
MODIS	2,330 km	250/500/ 1000 m	2000-now	Daily/ weekly/ 16days/ monthly composite	[1]https://earthexplorer.usgs.gov/
Landsat TM, ETM	185 km	30 m	1982-2011	16 days	https://earthexplorer.usgs.gov/
Landsat 8 OLI/TIRS	185 km	30 m	2013-now	16 days	https://earthexplorer.usgs.gov/
SPOT	60/117 km	10/20 m	1986-now	26 days	https://earthexplorer.usgs.gov/
Sentinel 3	1270 km	10 m	2016-now	<3 days	https://scihub.copernicus.eu/
LISS III	141 km	23.5 m	2006-now	24	[1]http://bhuvan-noeda.nrsc.gov.in/ data/download/
LISS IV	70 km	5.8 m	2006-now	5	
AWiFS	740 km	56 m	2006-now	5	
Commercial satellites (Available through vendors on payment basis)					
Ikonos	11/14 km	1/4 m	2000-now	3 days	https://www.digitalglobe.com
Quickbird	17 km	2.5 m	2001-now	Tasked	https://www.digitalglobe.com
Worldview 3	13 km	0.60-1.00 m	2014-now	<1 day	https://www.digitalglobe.com
Worlview 4	13 km	0.30 m	2016-now	<1day	https://www.digitalglobe.com
GeoEye	15 km	0.4-1.0 m	2008-now	2.6 days	https://www.digitalglobe.com
Hyperspectral Images					
Hyperion	7.7 km	30 m	2000-now	16 days	https://earthexplorer.usgs.gov/
AVIRIS	11 km	4-20 m	1992-now	16 days	https://aviris.jpl.nasa.gov/
HysIS	30 km	30 m	Nov 2018*	--	https://www.nrsc.gov.in/

**Launched on 29th November, 2018 and data yet not available*

[1]USGS- LP DAAC and Earth Explorer, and NRSC Bhuvan provides freely downloadable data archive

Hard classification is a Boolean representation of pixel where pixels are assigned to just one single class whereas in soft classification pixel represents the degree of association of pixel to different classes. Hard classification is more useful for the pure patches as this gives low accuracy in a heterogeneous area, hence for classifying heterogeneous area soft classification is preferred. The classification of remotely sensed images for the separation of objects can also be categorized as supervised and unsupervised. In supervised classification, users provide training sites signature of the pixels used for the classification by the system; while in unsupervised classification, computer classifies the pixels into the desired number of classes at its own and then the classes are assigned to respective groups by the user (Badaru, 2014). Maximum likelihood classifier is a supervised classification technique used for mapping invasive species which classifies the pixels on the basis of its probability to represent a class (Forsyth *et al.*, 2014). Spectral angle mapper is another supervised classifier that examines the similarity between reference spectra and ground spectra and measures their angles in 'n' dimensional plains, where smaller angles mean closer relationship (Adam *et al.*, 2017; Narumalani *et al.*, 2009). Another pixel based unsupervised classification that is not much used for invasive mapping includes iterative self-organizing data analysis (Rowlinson *et al.*, 1999).

Time series analyses using multiple time imageries is used to monitor the spread of invasion and associated effects (Evangelista *et al.*, 2009). Time series analysis increases the accuracy of classifiers and helps in the distinction of invasive species from the surrounding background (He *et al.*, 2011). A limited attempt has been made in India for the direct application of remote sensing tools for mapping invasive species (Dutta and Reddy, 2016; Jadhav *et al.*, 1993; Kimothi *et al.*, 2010; Kimothi and Dasari, 2010; Padalia *et al.*, 2013).This could be due to the limited opportunity provided by the freely available satellite imageries with coarser spatial resolution in limited spectral bands.

The limited availability of high spatial and spectral resolution imagery has been substituted by the combination of two or more imageries, newer classification techniques and modelling approaches for mapping species with better accuracy (Ghulam *et al.*, 2014; Kimothi *et al.*, 2010; Kimothi and Dasari, 2010; Shouse *et al.*, 2012; Srivastava *et al.*, 2018). Distinctive phenological attributes of the invasive plants and the surrounding plants can also be capitalized for detection and mapping invasive plants (Pouteau *et al.*, 2011). Detection of invasive species on the basis of its relationship with other guiding factors of establishment such as climatic variables, terrain features, etc. can be used for mapping the invasion (Adhikari *et al.*, 2015; Choudhury *et al.*, 2016; Padalia *et al.*, 2014; Padalia and Bahuguna, 2017; Panda *et al.*, 2018). Conventional remote sensing approaches can map the dominant canopy while the invasive species are very often sub-canopy invaders (Joshi *et al.*, 2006). Use of multi-angle sensors can detect forest vertical profile and invasive species (Ghulam *et al.*, 2014; Huang and Asner, 2009). On the other hand, selection of imagery for mapping invasive species below the canopy of native plants may be targeted during the season when the top canopy has leaf shading. However, the detection of herbaceous and understory plants is still a challenging task using remote sensing (Huang and Asner, 2009).

Application of LiDAR based remote sensing provides three dimensional structure of the vegetation and to a limited extent can help in detecting invasive species when there is a significant difference in the structure of the background vegetation and the targeted invasive species. The use of LiDAR in combination with other imageries helps to distinguish invasive plants (Huang and Asner, 2009). In order to combine any two imageries for successful mapping of invasion, the selected imageries preferably should be of the same time period (Asner *et al.*, 2008).

Hyperspectral images that capture information in multiple narrow bands have been quite useful in the detection and mapping of invasive species (He *et al.*, 2011). The hyperspectral sensors which are airborne have better performance over the satellite based observation which has limited spatial resolution. Hyperion, a space-borne hyperspectral based sensor can be used in combination with high spatial resolution imageries for the detection of invasive species (Shouse *et al.*, 2012). The use of hyperspectral helps in developing detailed species-specific spectral profiles and are used for species level identification (Huang and Asner, 2009) and has better classification accuracy over multispectral imagery (Underwood *et al.*, 2007).

There are other multiple methods that use a range of parametric (supervised and unsupervised) and non-parametric approaches that can be tested and applied for mapping invasion. Application of tools like support vector machine, logistic regression models, decision tree, spectral un-mixing, texture analysis, vegetation indices, object-oriented classification, simulation models, phenology metrics, landscape-based analysis, artificial intelligence, etc. that integrates remotely sensed data can be attempted for mapping invasion.

THE CURRENT STATE OF REMOTE SENSING APPLICATIONS FOR MAPPING INVASIVE PLANTS IN THE INDIAN CONTEXT

While there have been many attempts for utilizing remotely sensed data for mapping dominant vegetation over world, at the same time, there is limited attempts in utilizing the remote sensing data for mapping invasive plants in India. Most of the available literature from India has mapped the species on the selective basis either for single species or just for a smaller patch. Few studies utilized indirect methods to map the probable sites of invasion for a larger area and for more number of species. These studies have used modelling approaches. Models were trained for establishing the relationship between the presence locations of the species and the guiding factors that supports the establishment of the species. The present section discusses the various attempts made by the Indian researchers in the direction of mapping invasive plants using remote sensing. The various available literatures on mapping invasive species are also summarized in Table 3.

The early attempts traceable while reviewing the available literature of remote sensing application for mapping invasive plants is by Jadhav *et al.* (1993). They aimed to standardize the methodology for monitoring and mapping of Grassland together with mapping invasion of *Prosopis juliflora* and salinity ingress using satellite data for the Banni Grassland Reserve, Kutch, Gujarat. They used Landsat-MSS (1980), Landsat-TM (1985) and IRS-IA LISS I & II (1988) satellite data for invasion mapping.

Kimothi *et al.* (2010) evaluated the utility of Indian Remote Sensing (IRS) Satellite data for the detection and mapping of *Lantana camara* (an invasive weed) in Sal *(Shorea robusta)* dominant part of Rajaji National Park, Uttarakhand. They found that the merged products of IRS LISS-IV and Cartosat-1 were able to map the weed more effectively in comparison to the products in isolation. The highest accuracy in mapping was achieved by the merged product (96.4%) followed by alone utilization of LISS-IV (92.9%) and Cartosat-1 (65%). Kimothi and Dasari (2010) attempted to explore the feasibility of developing a semi-automated process to map and analyze Lantana using IRS data.

Padalia *et al.* (2013) applied spectral un-mixing techniques for discrimination of *Hyptis suaveolens* invasion at sub-pixel level using Earth Observation (EO-1) Advanced Land Imager (ALI) satellite data for the Doon valley and Shiwalik region of Dehradun, Uttarakhand. They utilized "Jeffries–Matusita spectral separability" analysis for the identification of the optimal period to distinguish Hyptis signature from surrounding background. Late October and early November were reported as the best period for the separation of signature and mapping of Hyptis using ALI data.

Padalia *et al.* (2014) used an indirect method to map the potential invasion sites of Hyptis where mapping was done on the basis of establishing a relationship between the presence locations of Hyptis with the predictor climatic and non-climatic variables for entire India. They utilized two species distribution models, viz., MaxEnt (Phillips *et al.*, 2006) and GARP (Stockwell and Peters, 1999) and compared the predictive capacity to map the invasion sites accurately. They observed better performance of MaxEnt over GARP for the whole of India while the prediction was more accurate for Central India and Western Himalayan foothills in comparison to Chottanagpur, Vidhayans region, Deccan Plateaus and North-East India.

Adhikari *et al.* (2015) mapped hotspots of invasive plants for entire India using 155 invasive species occurrence data derived from Global Biodiversity Information Facility (GBIF) (www.gbif.org). They modelled the potential sites using

Bioclimatic variables (www.worldclim.org), Ecoregion (www.maps.tnc.org/) and Anthropogenic biome (www.sedac.ciesin.columbia.edu/) as the predictor variables at a spatial resolution of 0.04° (?4 km) using MaxEnt model. They modelled highly suitable regions governed by the bioclimatic variables and intersected these regions with anthropogenic biomes and ecoregions of the country and categorized these areas as "Hotspot" of alien plant invasion. They identified 19 out of 47 ecoregions as hotspot of invasion.

Pasha et al. (2015) utilized multi-temporal images for the period 1977-2011 to map the temporal invasion rate of Mesquite *(Prosopis juliflora)* in Wild Ass Wildlife Sanctuary of Great Rann of Kutch, Gujarat. They successfully used multispectral Landsat MSS, Landsat TM, Landsat ETM and IRS P6 LISS III images to map the invasion rate. They estimated annual expansion rate of invasion in the range of 1.66-6.87.

Padalia *et al.* (2015) used MaxEnt model to map the potential sites of invasion by Hyptis under future climate change scenario of the year 2050 for North America, South America, Africa, Southeast Asia and Australia. They used GBIF archive of presence locations and data from national biodiversity inventory (http://bis.iirs.gov.in/bid1.php) of Hyptis and 20 environmental variables at a grid size of 5 km.

Choudhury *et al.* (2016) used MaxEnt to model the probable distribution of two invasive plants, viz., *Mimosa diplotricha* and *Mikania micrantha* in Rajiv Gandhi Orang National Park, Assam which represents protected tropical grassland.

Padalia and Bahuguna (2017) used MaxEnt model to predict the hotspots of multiple invasive plants with occurrences of 98 selected invasive species for the part of central India represented by Deccan Peninsula (Central highlands, Central plateau, Chotta-Nagpur and Eastern highlands,) and Semi-arid zones of Rajputana province.

Panda *et al.* (2018) used three different models (MaxEnt, generalised additive model and generalised linear model) to predict the current pattern and future risks of invasion by *Cassia tora* and *Lantana camara* under projected climate change scenario for the year 2050 and 2100 for entire India.

Table 3. *A brief account of selected research in India for mapping invasion using remote sensing*

Targeted Species	Study Region	Brief Description	Use of Remote Sensing	Reference
Prosopis juliflora	Banni Grassland Reserve, Kachchh, Gujarat.	Mapped grassland and invasion of *P. juliflora*.	Landsat-MSS (1980), Landsat-TM (1985) and IRS-IA LISS I & II (1988) satellite data used.	Jadhav et al. (1993)
Lantana camara	Part of Rajaji National Park, Uttarakhand.	Tested the accuracy of mapping using individual and merged satellite imagery.	IRS LISS-III, IV and Cartosat-1 images used.	Kimothi et al. (2010) Kimothi and Dasari (2010)
Hyptis suaveolens	Doon valley and Shiwalik region of Dehradun, Uttarakhand.	Sub-pixel level mapping using spectral un-mixing technique to detect Hyptis. They observed late October and early Nov. as the suitable period to detect Hyptis.	Earth Observation (EO-1) Advanced Land Imager (ALI) satellite data used for Sub-pixel level mapping using spectral un-mixing technique.	Padalia *et al.* (2013)

Hyptis suaveolens	Entire India.	Compared mapping accuracy of two species distribution model, viz., MaxEnt (Phillips *et al.*, 2006) & GARP (Stockwell and Peters, 1999).	Indirect use of remote sensing where satellite derived predictive variables were used.	Padalia *et al.* (2014)
155 invasive species	Entire India.	Used MaxEnt model to map hotspot of invasion.	Indirect use of remote sensing.	Adhikari *et al.* (2015)
Prosopis juliflora	Wild Ass Wildlife Sanctuary of Great Rann of Kutch, Gujarat	Mapped rate of invasion over a period of 1977-2011 using multi-temporal satellite imagery.	Multispectral Landsat MSS, Landsat TM, Landsat ETM and IRS P6 LISS III images used.	Pasha *et al.* (2015)
Hyptis suaveolens	North America, South America, Africa, Southeast Asia and Australia	Mapped potential sites of invasion under future climate change scenario of year 2050 using MaxEnt.	Indirect use of remote sensing.	Padalia *et al.* (2015)
Mimosa diplotricha and *Mikania micrantha*	Rajiv Gandhi Orang National Park, Assam	Modelled the prob--able distribution of invasion using MaxEnt.	Indirect use of remote sensing.	Choudhury *et al.* (2016)
98 invasive species	Part of central India represented by Deccan Peninsula.	Modelled hotspots of invasion using MaxEnt.	Indirect use of remote sensing.	Padalia and Bahuguna (2017)
Cassia tora and *Lantana camara*	Entire India.	Used MaxEnt, generalised additive model and generalised linear model to map current pattern and future risks of invasion under climate change scenarios of year 2050 and 2100.	Indirect use of remote sensing.	Panda *et al.* (2018)

CHALLENGES FOR MAPPING INVASIVE ALIEN PLANTS USING REMOTE SENSING: GAPS AND LIMITATIONS

The use of remote sensing has evolved much in recent decade and varieties of satellites with rapid revisit times provide imagery of global coverage (Table 2). However, the use of available images has not yet utilized time series data to a significant extent. There is ample scope for utilizing time series data for retrieval of continuous information for various stages of invasion. Mapping invasive alien plant species particularly in heterogeneous spread comprising of mixed species has been a continuous challenge. This becomes more challenging in a forested landscape where invasive species are generally found at sub-canopy level (Joshi *et al.*, 2006). The complexity of detecting a targeted species increases when a large number of species in a region send multiple background signals captured by a sensor. The mixing of signals in a forest area is contributed by horizontal as well as the vertical profile of the species. Both profiles are often not homogeneous in form thus sending mixed signals. This deteriorates the separation capability of a sensor. The capability of the sensor to detect individual plant and separate it from the associate species is difficult when the spatial and spectral resolution of a sensor is not adequate. Detection of individual species demands high spectral and spatial resolution imageries which are generally not available and are often a costly affair. Therefore, there is a need to evolve cost effective methods to map the individual species. The effort is needed to improve the mapping accuracy using coarser resolution images under the prevailing data scarcity of high resolution imageries.

Multispectral remote sensing with coarse and medium spatial resolutions has been applied successfully to map individual invasive populations with distinctive spectral signature and large spatial extent. Multispectral remote sensing acquired in Very High Resolution (VHR) categories such as World View and Cartosat-2 series can discern invasive plant with unique spectral signature and occurring at small spatial extent. However, invasive species with a subtle difference in spectral signature from the surrounding species are difficult to differentiate on the account of low spectral resolution of multispectral sensors (He *et al.*, 2011). Therefore, the use of hyperspectral images with finer spectral resolution is more successful. Hyperspectral sensors offer great potential to detect and map invasive plants; however, they are costly and are not freely available for the desired place and choice of time. The use of Hyperspectral images for mapping invasive species or other species has not been exploited much in India. It has not been used for a larger extent and has mostly been applied for localized small areas. Hyperspectral sensors on airborne flights provide less spatial coverage compared to the space borne sensors but have better spatial resolution thus they are more successful in mapping invasion. However, the prevailing policy of restriction for the airborne flights is yet an additional hindrance in the direction of full utilization of the opportunity. Another problem associated with hyperspectral sensing is posed by different phenological stages forming a different spectral signature for the same plant. Therefore, the user must be well informed about the appropriate time for detecting a species using a hyperspectral sensor. Moreover, hyperspectral data are voluminous as they have a large number of bands, this makes the processing of images a cumbersome task and is time consuming process (He *et al.*, 2011). Low signal-noise ratio makes the data much difficult to process for species detection. The pattern in the data for detecting species is difficult to understand for a novice person and a user need to have the spectral library of a species for its detection. There is a dearth of library availability for many of the species and this limits the use of hyperspectral images for species detection.

Many of the invasive plants have smaller forms belonging to herb or shrub categories. At the same time, they often represent low abundance and heterogeneous mixed population in smaller patches which makes them difficult to map using conventional classification techniques. There is a need to the test variety of approaches other than conventional methodologies such as linear spectral unmixing used by Padalia *et al.*, (2013).

RECENT ADVANCEMENTS AND NEW DIMENSIONS OF MAPPING INVASIVE ALIEN PLANTS: THE WAY FORWARD

Recent advancement in the use of remote sensing for mapping invasive plants relates to the use of both direct as well as indirect applications. The direct applications involve sensor based information to detect and map the species while the indirect ways imply establishing a relationship of selected attributes of a species (such as its presence) with associated variables guiding the establishment of species. Application of machine learning based models has widely been used for mapping individual species extent such as the MaxEnt. Other species distribution modelling approach has also been attempted to a limited extent. The MaxEnt is in vogue in India for mapping potential sites of invasion under present as well as future scenario (Table 3). The model is reported to perform reasonably well with better accuracy. Bradley (2014) reviewed spectral, textural and phenological approaches for detecting invasive plants. The review suggested that many modelling attempts using remote sensing based predictor set of variables performed well and were able to map the actual species distribution rather than mapping probable prediction of habitat suitability. Species distribution modelling provides an early opportunity for managers to take preventive actions in the areas highly prone to invasion. These models use various remotely sensed data products as the predictor set of variables. However, the models that integrate hyperspectral data for mapping is yet less explored (He *et al.*, 2011).

Model testing, their calibration and development into advanced version could be assisted by the data derived from the remote sensing. Combinations of sensors, fusion of images, sub-pixel analysis using spectral unmixing and fine-tuning of available methodologies are the need of the hour. Advance sensors such as LiDAR or RADAR and space borne hyperspectral sensors can be utilized for the detection and mapping of invasive plants. India has recently launched HysIS, a space borne hyperspectral sensor which is expected to fulfill the data requirement for mapping invasion. This may overcome the existing challenges inherited by the conventional ways of mapping using multispectral sensors. Innovative approaches and newer technologies are needed for the detection and mapping of invasive plants at economical and simplified ways.

Process based mechanistic models may be developed that can be parameterised for various growth stages using remote sensing data. Remote sensing can assist in development of these models by providing various prerequisite information on land characteristic, phenological stages, population structure and dynamics, photoperiod, utilization of photosynthetically active wavelengths of Sun energy spectrum, etc. Similarly, Plant functional traits that guide invasion can be studied using remote sensing.

The spatial pattern of invasive plants and their future spread in the landscape can be better understood combining landscape ecological indices and field observations. Studies have highlighted the role of spatial heterogeneity as a controlling factor for invasive plant richness. High landscape heterogeneity and fragmentation promotes invasion of an area by a variety of invasive plants. Landscape ecological indices can be derived at different spatial scales from remote sensing derived vegetation type and species maps.

Unmanned Aerial Vehicle (UAV) offers an unprecedented opportunity to map and monitor invasive at a very high spatial resolution and temporal frequency. Some of the State forest departments (such as Uttarakhand) have already initiated the use of UAVs for monitoring forests which can be further utilized for monitoring noxious weeds in the country. The future development in UAV based cameras with lesser weight and higher resolving power can immensely benefit invasive species management.

The Google Earth Engine (https://earthengine.google.com/) is yet another promising and emerging web based tool that provides free access to petabyte-scale archives of remote sensing data (Gorelick *et al.*, 2017). It is a cloud-based platform that gives access to high performance computing for processing large datasets without demanding any image processing specialized software or high performing computer desktop. However, being a new launch, the orientation of this platform is less towards the mapping of invasive species. Looking at the enraging needs of mapping invasion, it is expected that the Google Earth Engine would provide an opportunity to map invasion, sooner or later.

The crowd sourcing tools such as smartphone based mobile apps offer an alternate opportunity to collect data on invasive, which otherwise are difficult to map using remote sensing, through public participation (citizen science). These mobile-based tools can help in the systematic collection of data on occurrence of species and integration of data with web-based information system in real time using GIS and Global Navigation Satellite System (GNSS).

CONCLUSION

Invasive alien plants pose a great threat to the biodiversity. The prevention and eradication of invasion are one of the top priorities for the conservation of habitats of native indigenous plants. This provides an opportunity to detect and map invasive species. Field based observation to map the invasion is now supported by remote sensing. Remote sensing provides mapping for a larger extent in an economical way with lesser effort. Space borne remote sensing provides multi-temporal repeated observation that can be utilized for monitoring the rate of expansion and pathways of invasion. There has been diverse application of remote sensing ranging from multispectral to hyperspectral for the invasion mapping. Application of remote sensing involves direct interpretation of images captured by remote sensing sensors to detect the invasive plants while there is indirect application also. An indirect application involves establishment of relationship of occurrence of species guided by the environmental variables using modelling tools. The predictor sets of variables in these modelling approaches are often acquired through remote sensing. There have been extensive uses of remote sensing for the mapping of dominant vegetation types in India. However, mapping of invasion using remote sensing has been limited in lack of availability of images of higher spatial and spectral resolution appropriate for invasion mapping. The higher resolution images are not freely available and are usually costly. This demands development of newer approaches and methodologies to overcome the paucity of data. Future research for applying remote sensing should involve the development of economical and simpler ways of mapping invasion without compromising with the level of accuracy.

REFERENCES

Adam, Y., Ngetar, N.S. and Ramdhani, S. (2017). The assessment of invasive alien plant species removal programs using remote sensing and GIS in two selected reserves in the eThekwini Municipality, KwaZulu-Natal, South African J. Geomatics, 6: 90-105.

Adhikari, D., Tiwary, R. and Barik, S.K. (2015). Modelling hotspots for invasive alien plants in India, PLoS One.

Asner, G.P., Jones, M.O., Martin, R.E., Knapp, D.E. and Hughes, R.F., (2008). Remote sensing of native and invasive species in Hawaiian forests, Remote Sens. Environ, 112: 1912-1926.

Atzberger, C. and Eilers, P.H.C. (2011). A time series for monitoring vegetation activity and phenology at 10-daily time steps covering large parts of South America, Int. J. Digit. Earth, 4: 365-386.

Badaru, Y.U. (2014). Accuracy Assessment of Image Classification Algorithms, J. Nat. Sciences Res., 4: 1-5.

Boyd, D.S. and Foody, G.M. (2011). An overview of recent remote sensing and GIS based research in ecological informatics, Ecol. Inform., 6: 25-36.

Bradley, B.A. (2014). Remote detection of invasive plants: A review of spectral, textural and phenological approaches, Biol. Invasions.

Calviño-Cancela, M., Méndez-Rial, R., Reguera-Salgado, J. and Martín-Herrero, J. (2014). Alien plant monitoring with ultralight airborne imaging spectroscopy, PLoS One.

Carreiras, J.M.B., Pereira, J.M.C., Campagnolo, M.L. and Shimabukuro, Y.E. (2006). Assessing the extent of agriculture/pasture and secondary succession forest in the Brazilian Legal Amazon using SPOT VEGETATION data, Remote Sens. Environ., 101: 283-298.

Choudhury, M.R., Deb, P., Singha, H., Chakdar, B. and Medhi, M. (2016). Predicting the probable distribution and threat of invasive *Mimosa diplotricha* Suavalle and *Mikania micrantha* Kunth in a protected tropical grassland, Ecol. Eng.

Cohen, W.B. and Goward, S.N. (2004). Landsat's role in ecological applications of remote sensing, AIBS Bull, 54: 535-545.

Corbane, C., Lang, S., Pipkins, K., Alleaume, S., Deshayes, M., Millán, V.E.G., Strasser, T., Borre, J. Vanden, Toon, S. and Michael, F. (2015). Remote sensing for mapping natural habitats and their conservation status–New opportunities and challenges, Int. J. Appl. Earth Obs. Geoinf., 37: 7-16.

Cuneo, P., Jacobson, C.R. and Leishman, M.R. (2009). Landscape-scale detection and mapping of invasive African Olive *(Olea europaea* L. ssp. *cuspidata* Wall ex G. Don Ciferri) in SW Sydney, Australia using satellite remote sensing, Appl. Veg. Sci.

Evangelista, P.H., Stohlgren, T.J., Morisette, J.T. and Kumar, S. (2009). Remote Sensing Mapping Invasive Tamarisk (Tamarix): A comparison of single-scene and time-series analyses of remotely sensed data, Remote Sens., 1: 519-533.

Dutta, K. and Reddy, C, S. (2016). Geospatial Analysis of Reed Bamboo *(Ochlandra travancorica)* Invasion in Western Ghats, India. Journal of the Indian Society of Remote Sensing, 44.

Forsyth, A.T., Gibson, L.A. and Turner, A.A. (2014). Assessment of SPOT 6 imagery for mapping the invasive alien plant species Pinus spp. in a mountainous area of the Western Cape,Proc. Second AfricaGEO Conf.

FSI, (2011). Forest types of India. Forest Survey of India, Ministry of Environment, Forest and Climate Change, Government of India, Dehradun.

Ghulam, A., Porton, I. and Freeman, K. (2014). Detecting subcanopy invasive plant species in tropical rainforest by integrating optical and microwave (InSAR/PolInSAR) remote sensing data, and a decision tree algorithm, ISPRS J. Photogramm. Remote Sens.

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D. and Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone, Remote Sens. Environ.

Han, K., Champeaux, J.-L. and Roujean, J.L. (2004). A land cover classification product over France at 1 km resolution using SPOT4/VEGETATION data, Remote Sens. Environ. 92: 52-66.

He, K.S., Rocchini, D., Neteler, M. and Nagendra, H. (2011). Benefits of hyperspectral remote sensing for tracking plant invasions, Divers. Distrib.

Huang, C. ying and Asner, G.P. (2009). Applications of remote sensing to alien invasive plant studies, Sensors (Switzerland).

IIRS, (2002). Biodiversity characterisation at landscape level in Western Himalayas, India using satellite remote sensing and geographic information system, Indian Institute of Remote Sensing, Dehradun.

ISFR, (2017). India State of Forest Report. Forest Survey of India, Ministry of Environment, Forest and Climate Change, Government of India, Dehradun.

Jadhav, R.N., Kimothi, M.M. and Kandya, A.K. (1993). Grassland mapping/monitoring of Banni, Kachchh (Gujarat) using remotely-sensed data, Int. J. Remote Sens.

Joshi, C., De Leeuw, J., Van Andel, J., Skidmore, A.K., Lekhak, H.D., Van Duren, I.C. and Norbu, N. (2006). Indirect remote sensing of a cryptic forest understorey invasive species, For. Ecol. Manage.

Kimothi, M.M., Anitha, D., Vasistha, H.B., Soni, P. and Chandola, S.K. (2010). Remote sensing to map the invasive weed, Lantana camara in forests, Trop. Ecol., 51: 67-74.

Kimothi, M.M. and Dasari, A. (2010). Methodology to map the spread of an invasive plant *(Lantana camara* l.) in forest ecosystems using Indian remote sensing satellite data, Int. J. Remote Sens., 31: 3273-3289.

King, M.D., Kaufman, Y.J., Menzel, W.P. and Tanré, D. (1992). Remote sensing of cloud, aerosol, and water vapor properties from the moderate resolution imaging spectrometer (MODIS), IEEE Trans. Geosci. Remote Sens., 30, 2:27.

Lass, L.W., Prather, T.S., Glenn, N.F., Weber, K.T., Mundt, J.T. and Pettingill, J. (2005). A review of remote sensing of invasive weeds and example of the early detection of spotted knapweed *(Centaurea maculosa)* and babysbreath *(Gypsophila paniculata)* with a hyperspectral sensor, Weed Sci., 53: 242-251.

Lillesand, T., Kiefer, R.W. and Chipman, J. (2014). Remote Sensing and Image Interpretation. John Wiley and Sons, Hoboken.

Narumalani, S., Mishra, D.R., Wilson, R., Reece, P. and Kohler, A. (2009). Detecting and mapping four invasive species along the floodplain of North platte river, Nebraska, Weed Technol., 23: 99-107.

Padalia, H. and Bahuguna, U. (2017). Spatial modelling of congruence of native biodiversity and potential hotspots of forest invasive species (FIS) in central Indian landscape, J. Nat. Conserv, 36, 29-37.

Padalia, H., Kudrat, M. and Sharma, K.P. (2013). Mapping sub-pixel occurrence of an alien invasive *Hyptis suaveolens* (L.) Poit. using spectral unmixing technique, Int. J. Remote Sens., 34: 325-340.

Padalia, H., Srivastava, V. and Kushwaha, S.P.S. (2014). Modeling potential invasion range of alien invasive species, *Hyptis suaveolens* (L.) Poit. in India: Comparison of MaxEnt and GARP, Ecol. Inform., 22: 36-43.

Padalia, H., Srivastava, V. and Kushwaha, S.P.S. (2015). How climate change might influence the potential distribution of weed, bushmint *(Hyptis suaveolens)*? Environ. Monit. Assess. 187, 210.

Panda, R.M., Behera, M.D. and Roy, P.S. (2018). Assessing distributions of two invasive species of contrasting habits in future climate, J. Environ. Manage., 213: 478-488.

Pasha, S.V., Satish, K. V., Reddy, C.S. and Jha, C.S. (2015). Massive invasion of mesquite *(Prosopis juliflora)* in wild ass wildlife sanctuary, India. Natl. Acad. Sci. Lett., 38: 271-273.

Phillips, S.J., Anderson, R.P. and Schapire, R.E. (2006). Maximum entropy modeling of species geographic distributions, Ecol. Modell., 190: 231-259.

Pouteau, R., Meyer, J.Y. and Stoll, B. (2011). A SVM-based model for predicting distribution of the invasive tree *Miconia calvescens* in tropical rainforests, Ecol. Modell., 222: 2631-2641.

Rowlinson, L.C., Summerton, M. and Ahmed, F. (1999). Comparison of remote sensing data sources and techniques for identifying and classifying alien invasive vegetation in riparian zones, Water SA, 25: 497-500.

Shouse, M., Liang, L. and Fei, S.(2012). Identification of understory invasive exotic plants with remote sensing: In urban forests, Int. J. Appl. Earth Obs. Geoinf., 21: 525-534.

Srivastava, Vivek, Lafond, Valentine and Griess, Verena. (2019). Species distribution models (SDM): applications, benefits and challenges in invasive species management. CAB Reviews Perspectives in Agriculture Veterinary Science Nutrition and Natural Resources.

Stockwell, D. and Peters, D. (1999). The GARP modelling system: Problems and solutions to automated spatial prediction, Int. J. Geogr. Inf. Sci., 13: 143-158.

Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E. and Steininger, M. (2003). Remote sensing for biodiversity science and conservation, Trends Ecol. Evol., 18: 306-314.

Underwood, E.C., Ustin, S.L. and Ramirez, C.M. (2007). A comparison of spatial and spectral image resolution for mapping invasive plants in coastal California, Environ. Manage., 39, 63-83.

3 SPECIES DISTRIBUTION MODELS FOR MANAGEMENT OF INVASIVE ALIEN SPECIES

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INTRODUCTION

The spread of various invasive species continues to increase and this has pose serious threat to the native species and ecosystem and an important cause to species extinction. Alien species which locally becomes dominant and invade natural communities, are referred to as invasive species. In an established ecosystem, there is a natural balance, and the plants and animals within these systems find this balance suitable for their survival. Invasive species can reduce biodiversity, degrade habitats and alter native, transmit exotic diseases to native species, and further put at risk to threatened and endangered plants and animals. Invasive species, owing to their aggressive nature can expand their zone of occupancy in quick succession, spread over large tracts, and endanger the natural elements of flora and bring about abrupt changes in floristic composition.

The impacts of invasive species are felt from the local to the global scale and researchers, managers, and the common public is becoming more aware of invasive plant impacts with its increased risk on environment as well as threat on local and global economy. Since, the United Nations Summit in Rio de Janeiro, 1992, invasive species have come to be regarded as one of the main reasons for the loss of biodiversity (Keane and Crawley, 2002; OECD, 96). Apart from the ecological difficulties in explaining how the species become invasive, growing concern surrounds the socio-economic aspects of the issue as well. The change in land-use pattern breaks natural barrier and aids to increasing dispersion rates of invasive species (Naylor, 2000). The problem is likely to worsen with time due to climate changes and expanding world trade which promotes species migrations widely and rapidly across natural geographic barriers through air, land and sea. It is estimated through various studies that India occurring one of the highest annual environmental costs US$ 25.0 billion for invasion followed by United States - US$ 58.0 billion (Pimentel et al., 2000). Statistics of loss for some of the other countries include South Africa $7 billion, UK $ 12 billion and Brazil $50 billion. The ecological, social and economic effects combined together alters native regimes beyond range of variation which has little prospect of reversal (Vila and Ibanez, 2011).

Over the years, Species Distribution Models (SDMs) have been widely and very effectively applied to address many environmental issues including species suitability studies, probability of spread of disease, biodiversity conservation and to map spatial extent of invasive species distribution. Monitoring and to map probability distribution of an invasive species numerous empirical models exist. A few of these approaches which uses species presence only records are, Bioclimatic envelope method (Bioclim), Generalized Additive model (GAM), Artificial Neural Networks (ANN) and regression trees. Ecological niche based approach offers several algorithms such as Maximum Entropy (Maxent), Genetic Algorithm for Rule set Prediction (GARP), Biomapper and Climex that can be used in deriving potential distribution niche of invasive species.

SPECIES DISTRIBUTION MODELS

Species Distribution Models (SDMs) or Ecological Niche Model, as their name suggests, are based on correlation between bioclimatic variables, and the occurrence of species in a particular environmental niche along with other geographical factors constraining species distribution. The model, simulate the distribution of species and their ranges relative to these bioclimatic variables from a set of known presence data of the species. The species distribution scenario can also be simulated for future bioclimatic conditions, and output produced helps to compare the status of present distribution scenario of a species with that of future distribution pattern and to analyze how the species distribution may shift over the period of time under varying climatic conditions. The output of an SDM is in the form of distribution map species' simulated range, for both the present and the future scenario. As many available datasets do not provide reliable information about species absences, several presence-only based analyses have been developed. Various GIS modes including MAXENT, GARP, Biomapper, Bioclim, DivaGIS, Climex have been used widely to address diverse category of environmental issues involving species or habitat suitability studies on regional as well as global. But, MAXENT due to its robustness and good technical document support has been mostly preferred by the research community.

Maxent Model (Maximum Entropy)

Maxent model follows maximum entropy approach to model suitability niches and distributions of species. This is based on presence only data assumption. The model expresses the suitability of each grid cell as a function of the bioclimatic variables at that particular grid cell. A high value of the function at a particular grid cell reflects that the grid will have preferable niche conditions for the distribution of the species under consideration. Under certain constraints on input data and geographical locations of species occurrence data, the output is interpreted as predicted probability of presence, or as predicted local abundance. From the simulated scenario, the selected distribution range must have the maximum entropy subject to some constraints, like it must have the same assumption for each derived feature as the average over selected sample points. Some of the benefit of this model is that it requires presence only data, unbiased predictions, explores complex relationship with environment and it is generative model and performs well even with limited set of data (Phillips, and Dudik, 2008).

SDM for prediction of invasive species- Indian Perspective

Over the years, the use of species distribution models has gained popularity and especially MAXENT (Maximum Entropy based model) has been widely used for mapping most probable distribution pattern of species. Globally several works are reported on use of niche model based approach for deducing the spatial distribution of invasive species. However, in Indian perspective Jaryan *et al.*, (2013) modelled the potential distribution of *Sapium sebiferum,* an invasive tree species in western Himalaya, and achieved area under curve (AUC) for receiving operators' analyses measured at all possible threshold values training (0.993) and test value 0.993 was close to 1, that shows the accuracy of the model. Priyanka *et al.*, (2013), projected the potential distribution of *Lantana camara,* in Jim Corbett and Rajaji national park, and reported the gregarious distribution of *L. camara* using three climatic change models CSIRO (Commonwealth Scientific and Industrial Research Organization), CCCM (Canadian Centre for Climate Modeling and Analysis) and HadCM3 (Hadley Centre for Climate Prediction and Research's General Circulation Model) across the time slices 2020 to 2080. In another study, Priyanka *et al.*, (2013), investigated the potential distribution of *L. camara* in Jim Corbett and Rajaji national park using Maxent, Biomapper and GARP and reported that Maxent successfully anticipated the most of potential distribution, but GARP and Biomapper projected odd pattern of over prediction and under prediction of distribution. A few other studies also used Species Distribution Models (SDMs) for mapping probable risks of invasion (Adhikari *et al.*, 2015; Choudhury *et al.*, 2016; Padalia *et al.*, 2014, 2015; Padalia and Bahuguna, 2017; Panda *et al.*, 2018; Srivastava *et al.*, 2018).

SDM for prediction of invasive species-ICFRE initiatives

Earlier attempts have been made mostly on documentation of invasive species on location based regional level. One such study was conducted by Institute of Forest Productivity for documentation of major invasive species in Latehar and Hajaribag district and 41 invasive alien species were reported in this study (Divakara *et.al,* 2013). Presently a project on risk assessment of potential distribution of *Lantana camara* in the state of Jharkhand is being carried out by

Institute of Forest Productivity, Ranchi. The project aims at modeling the present potential distribution of *Lantana camara* in the state of Jharkhand as well as prediction of future potential distribution of *Lantana camara* under varying climatic conditions by 2050. Further, another major initiative has been taken up by ICFRE for assessment and monitoring of Invasive Alien Plant Species in India and formulation of strategies for management of key Invasive Alien Plant Species *(Prosopis juliflora, Mikania micrantha, Lantana camara, and Acacia species)* in different regions of the country. During 2008, ICFRE has identified about 75 forest invasive species (FIS) in different parts of the country, which are a threat to the natural forest cover. The ICFRE's Biodiversity and Climate Change (BCC) division has prepared a country report on – Stocktaking of National Activities on FIS – which has been submitted by the Union ministry of Environment, Forests and Climate Change to Asia Pacific Forest Invasive Species Network (http://www.icfre.gov.in).

CONCLUSION

The growing frequency of invasive species incursions globally and its impact continue to affect biodiversity, ecological system, economies and human health at an alarming rate. Invasive alien species are continuously spreading into new regions at unprecedented pace. The problem is likely to worsen with time because of climatic changes that promote species migrations and expanding world trade that transports organisms both deliberately and unintentionally widely and rapidly across natural geographic barriers via air, land and sea traffic. Managing invasive species is thus becoming more daunting and will be a very tough and challenging process. Traditional approach of management does not involve the changing climatic scenario and thus does not portray the futuristic shifting pattern that may occur with the species distribution under varying climatic conditions. Risk analysis and impact assessments, identification and early detection, and monitoring and implementation of control measures are therefore highly dependent on the availability of valid and up-to-date information that can keep pace with new invasion threats. Thus, SDMs, that involves the correlation of bioclimatic parameters with the present occurrence of species, and simulate the future scenario under varying climatic conditions, has great potential in the identification of potential niches that is prone to future spread of invasion and these approach needs to be promoted. The future projections derived from such models can play very important role to analyze the shift in spread pattern of invasion and accordingly the management strategies can be timely planned, to control or curtail the invasion.

REFERENCES

Adhikari, D., Tiwary, R. and Barik, S.K. (2015). Modelling hotspots for invasive alien plants in India. PLoS One.

Choudhury, M.R., Deb, P., Singha, H., Chakdar, B. and Medhi, M. (2016). Predicting the probable distribution and threat of invasive *Mimosa diplotricha* Suavalle and *Mikania micrantha* Kunth in a protected tropical grassland, Ecol. Eng.

Divakara, B. N., Prasad, S. and Das, R. (2013). Documentation of Invasive Plant Species in Latehar and Hazaribagh Districts: Jharkhand-India, The Indian Forester, 139(2): 113-117.

Jarayan, V., Dutta, A., Uniyal, S., Kumar, A., Gupta, R. C. and Singh, R. D. (2013). Modelling potential distribution of *Sapium sebiferum* - an invasive tree species in western Himalaya. *Current science*, 105(9): 1282-1288.

Jayens, E. T. (1957). Information Theory and Statistical Mechanics, The Physical Review, 106 (4): 620-630.

Keane, R. M., and Crawley, M. J. (2002). Exotic Plant Invasions and the Enemy Release Hypothesis. Trends in Ecology and Evolution, 17: 164-169.

Naylor, R. L. (2000). The economics of alien species invasions. Pages. In: Invasive Species in a Changing World. Washington (DC), (Mooney HA, Hobbs RJ, Eds), Island Press, (241-259).

Padalia, H., Bahuguna, U. (2017). Spatial modelling of congruence of native biodiversity and potential hotspots of forest invasive species (FIS) in central Indian landscape, J. Nat. Conserv., 36: 29-37.

Padalia, H., Srivastava, V. and Kushwaha, S.P.S. (2014). Modeling potential invasion range of alien invasive species, *Hyptis suaveolens* (L.) Poit. in India: Comparison of MaxEnt and GARP, Ecol. Inform., 22: 36-43.

Padalia, H., Srivastava, V. and Kushwaha, S.P.S., (2015). How climate change might influence the potential distribution of weed, bushmint *(Hyptis suaveolens)*? Environ. Monit. Assess., 187, 210.

Panda, R.M., Behera, M.D. and Roy, P.S. (2018). Assessing distributions of two invasive species of contrasting habits in future climate, J. Environ. Manage., 213: 478-488.

Phillips, S.J. and Dudik, M. (2008). Modelling of species distributions with MaxEnt: new extensions and a comprehensive evaluation, Ecography, 31:161-175.

Pimentel, D., Lori, L., Rodolfo, Z., and Doug, M. (2000). Environmental and economic costs of non-indigenous species in the United States, BioScience, 50 (1):53-65.

Priyanka, N. and Joshi, P. K. (2013). Modeling spatial distribution of *Lantana camara*- A comparative Study; CJBAS,01(2): 100-117.

Priyanka, N. and Joshi, P.K. (2013). Effects of Climate Change on Invasion Potential Distribution of *Lantana camara.* J. Earth Sci. Clim. Change, 4:164.

Sinha, S. (2013). Modeling potential distribution ecological niche for selected endemic species in Darjeeling Hill, Thesis submitted for Master of Technology, Andhra University, Vishakhapatnam.

Srivastava, Vivek, Lafond, Valentine and Griess, Verena. (2019). Species distribution models (SDM): applications, benefits and challenges in invasive species management. CAB Reviews Perspectives in Agriculture Veterinary Science Nutrition and Natural Resources.

Vila and Ibanez. (2011). Plant invasions in the landscape, Landscape Ecology, 26(4):461- 472.

4 ECOLOGICAL IMPACTS OF INVASIVE ALIEN SPECIES

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INTRODUCTION

Introduction of invasive species often differ functionally from the composition of the recipient community and creating ecological imbalance across taxa and habitats. It also causes greater risks to the ecosystem services that are associated with the communities. Invasion of species is mostly facilitated by human activities. Given the increasing pace of human interaction across the globe, it becomes even more important to study and monitor the impacts that are altering biodiversity and ecosystem functioning. It has been also recorded that the negative impacts of invasive species affects the abundance and diversity at species level. These rapid changes of abundance and diversity of species may also lead to local extinctions (Kohli *et al.* 2004; Vila` *et al.*, 2006; Gaertner *et al.*, 2009; Hejda *et al.*, 2009; Powell *et al.*, 2011). The ecological impact of invasive plants over global biodiversity is second only to habitat fragmentation (Bhatt *et al.*, 2011).

Invasive plant species that proliferates abundantly and dominates an ecosystem is known to potentially influence the performance of individual resident species and their population dynamics (Vila` & Weiner 2004), subsequently, it will lead to direct and indirect effects on plant community structure and ecosystem functioning (Levine *et al.*, 2003). Sometimes invasive species, is also been reported to increase ecosystem productivity and alter the rate of nutrient cycling (Liao *et al.*, 2008; Ehrenfeld 2010), thereby impacting ecosystem services and human well-being (Pejchar and Mooney 2009). Although there are several studies carried to assess the ecological impact of invasive species on diversity, abundance and ecosystem. But our ability to predict when and where impacts might be most deleterious is limited.

Ecology, in recent times is often integrated with economy. Not only the ecological and environmental impact of invasive species is an important issue, economic costs involved with management and damage control cause considerable impact on economy. For example: annual costs in the Netherlands, the European Union and globally have been estimated to go up to 1.3 billion, 12.5 billion, and 1.4 trillion euro, respectively (D'hondt *et al.*, 2015). The estimated damage from invasive species worldwide totals more than 1.4 trillion USD, or five percent of the global economy (Pimentel *et al.*, 2005). The annual U.S. cost from invasives is estimated to be 120 billion USD, with more than 100 million acres affected (Pimentel *et al.*, 2001). The economic impact caused by the six invasive plants in Canada was predicted to be a minimum of 65 million USD in 2008, rising to 139 million USD by 2020 (Frid *et al.*, 2009). About 25 percent of Canada's endangered species, 31 percent of its threatened species and 16 percent of its vulnerable species are in some way at risk because of alien species. In the province of British Columbia and in other areas across Canada, invasive species have affected some of the most diverse native ecosystems, including wetlands and riparian forests, which are becoming increasingly imperilled. The state of Florida spends 56 million USD a year to manage one invasive species – *Hydrilla* sp. (Ashton and Rempel 2010). The economic dimension of the problem of invasive species is commonly seen with two perspectives. First, economics is vital to the cause of biological invasiveness, and the consequences of pest attack go far beyond direct damages or control costs. Most cases of invasiveness can be linked to the intended or unintended consequences of economic activities (Perrings, *et al.*, 2002).

INVASIVE SPECIES ALTERS ECOSYSTEM SERVICES AND BIODIVERSITY

The loss in biodiversity due to invasive species negatively impacts human well-being by lowering the gains from several ecosystem services (Diaz *et al.*, 2006). Few assessments indicates that invasive species have an effect on all three major sections of ecosystem services such as provisioning services, regulating and maintenance services and supporting services (Katsanevakis *et al.*, 2014). Few studies have also found a positive correlation between the number of impacts and the amount of ecosystem services affected. Examples of positive impacts of invasive species are prevention of erosion by Kudzu vines in the United States, or the Pacific oyster *Crassostrea gigas*, which is able to help in creating biogenic reefs, thus providing more opportunities for recreational fishing or diving. Moreover, many known invasive species (American mink - *Mustela vison*), Wakame *(Undaria pinnatifida)* are being cultivated or bred outside of their native habitat, providing economic profit. Some of the evidence of impacts which is soon noted is: fast seed germination, high population growth, early reproductive maturity, reproduction vegetatively as well as sexually, generalized pollination, wide tolerance to many habitat types, adaptation to disturbance, high rate of biomass accumulation, long-range seed dispersal capabilities, fruit used by wildlife (including humans), relative lack of predators or diseases in present location. They can alter nutrient cycling, local hydrology, fire regimes, geo-morphological processes (such as dune formation or stream profile), species and structural diversity, available wildlife resources, and prevent recruitment of native species due to competition for light, nutrients, and/or moisture.

In India, there are a number of invasive weeds which have caused menace to native biodiversity (Kohli *et al.*, 2009). Invasive species like *Ageratum conyzoides, Lantana camara* and *Parthenium hysterophorus* in the Shivalik hills of Himachal Pradesh seriously resulted in the reduction of species diversity, species richness and composition of the native vegetation (Dogra *et al.*, 2009). There was decline in valuable indigenous medicinal plants in the Shivaliks of Himachal Pradesh due to the invasion of *Ageratum conyzoides* (Dogra, 2008).In the dense forest interiors of the Gandhamardan Hill range, Orissa, Reddy and Pattanaik, (2009) reported *A. conyzoides* among 64 exotic species posing a serious threat to this forest area. The spread of this weed was found to conquer on the littoral and swamp forests of Assam where it was deteriorating the process of natural succession and reforestation to such an extent that some forests have lost their identity (DOEF, 2010).

Invasion of *A. conyzoides* have resulted in unevenness and instability of herb layers in the Mandhala watershed in Himachal Pradesh (Rana *et al.*, 2010). In fact it is also causing disruption and loss of vegetation in the reserve parks and Wildlife Sanctuaries like the Jim Corbett Tiger Reserve, Veerapuli and Kalamalai Forest Reserve in the Western Ghats and Mudumalai Wildlife Sanctuary (Rawat *et al.*, 1997; Swamy *et al.*, 2000; Silori and Mishra, 2001). Invasion of *Mikania micrantha* results in reduced plant species richness and seedling growth of rice in Western Ghats (Kaur *et al.,* 2012). *Chromolaena odorata,* one of the world's most dangerous tropical invasive weeds is known to decreases native plant species in the Western Ghats of India (Mangla *et al.*, 2008). *Lantana camara* creates a dense cover which leads to the reduction in the intensity and duration of light which prevents the establishment of tree species seedlings (Sharma and Raghubanshi, 2006). Invasion of *Lantana camara* have caused significant loss of species diversity and richness in Garhwal Himalayas Uttarakhand, India. Also, it was concluded that *L. camara* favours exotics over endemic species which needs further investigation (Dobhal *et al.*, 2010). Ekta, (2014) reported that *P. juliflora* reduced the growth of other native trees of the forest significantly in the Delhi ridge forest of semi-arid region. However recent study by Naudiyal *et al.*, (2017) doubts the general perception regarding *P. juliflora's* negative impact on biodiversity. While studying the plant community composition on Delhi ridge they found that factors like anthropogenic disturbances and grazing are causing significant negative impact on the vegetation diversity, rather than *P. juliflora*. Moreover they also found a positive correlation between *P. juliflora* and the native species concluding that *P. juliflora* acts as a nurse tree in facilitating the regeneration of native species under its canopy. Therefore it is necessary to carry out holistic research regarding the impacts of invasive plant species since impacts on native biodiversity may differ in relation to the different location or other local disturbances.

INVASIVE SPECIES ALTERS SOIL PROPERTIES

Invasive plants are capable of disturbing composition of nutrients and alter soil microbial community for their successful invasion in different habitats. These species can release compounds that alter nutrient availability including nitrogen and phosphorus and also alter topsoil (Dukes and Mooney, 2004). In the north and north-western part of India, Sharma and Dakshini, (1998) found that *Prosopis juliflora* is causing more soil degradation as compared to the native *P. cineraria* species. Though they are belonging to same genus yet showing different effects is a matter of discussion and therefore it is very important aspect to study soil and invasive plants interaction in different geographical regions in the country for drawing conclusion regarding the success for plant invasion. In addition there is also a need to study the biotic interactions among native plants and native soil biota (soil pathogens) for better understanding invasion pathway.

Allelopathy is one of the important mechanisms for the plant invasion. It is defined as the adverse effect of a plant on another plant through the release of several secondary metabolites by plant parts into the soil (Inderjit and Callaway, 2003). It is the natural phenomenon which can negatively or positively affect the physiology of other plants existing in their vicinity (Rice, 1984). Allelochemicals are present in different plant parts like leaf, stem, root or flower which can enter in soil through foliar leaching in rain water, leaf falling or may be due to exudation from roots into soil water which then incorporates into the soil (Inderjit and Duke, 2003). Therefore it is very important to test allelopathic effect of different plant parts to understand the invasion success. There are many studies which have reported about the allelopathic effect of invasive plant on seed germination and agricultural crops. *Parthenium* release allelochemicals like phenolics and sesquiterpenes which affects the crops and other native flora resulting inhibition of their growth and development (Kanchan and Jayachandra, 1980). Chellamuthu *et al.*, (1977) also reported about the reduction of germination percentage of field crops like gram and sorghum due to *P. juliflora*. Allelochemicals present in Lantana decrease the potential of native plants which ultimately results in poor productivity (Sharma *et al.*,1988) and in many forest rich parts of India they are also responsible for wild fire (Raghubanshi *et al.*, 2005). Allelopathic potential of Lantana disturbs regeneration process of other species by decreasing germination, reducing early growth rates and selectively increasing mortality of other plant species. The aqueous leaf extract of *Prosopis juliflora* reported to reduce seed germination and radical length of *Triticum aestivum* Var-Lok-1(Siddiqui *et al.*, 2009). Gantayet *et al.*, (2014) found that the leaf litter leachate and dust of *Lantana camara* was responsible for the poor establishment of seedlings, vegetative growth and yield of Green gram. Therefore there is a need to spread awareness among the farmers regarding the harmful effects of these allelochemicals on agriculture crops and their productivity.

Invasive species are also reported to alter the soil nutrient pools and processes in ecosystems that they invade by altering the quality and quantity of litter inputs (Sharma and Raghubanshi 2011). Their studies have shown the impact of vegetative understory invasions on soil nitrogen (N) availability in forest ecosystems. For example in the dry deciduous Vindhyan forest of India, it has been observed that the lantana litter inputs increase with increasing lantana cover and the chemical composition of lantana litter was also very much different from the native forest species litter. High N, low lignin content of the lantana litter and favorable microclimate beneath lantana canopy favored faster decomposition and release of N. This alteration in litter inputs and chemistry beneath the lantana canopy positively and significantly alters soil N availability, N-mineralization, and total soil N (Sharma and Raghubanshi 2011).

PROMINENT INVASIVE SPECIES AND ITS IMPACT

Earlier researches establishes that invasive species have significant negative (costs) and positive (benefits) impacts on socio-ecological systems and socioeconomic livelihoods (Tewari *et al.*, 2000; Zavaleta 2000; Pasiecznik *et al.*, 2001; Kohli *et al* 2004). In India, the invasion of alien plants is beset with ecological, economic and social consequences (Bhatt *et al.*, 2012). India being a tropical country bestowed with rich biodiversity and varied environmental conditions is highly vulnerable to invasive species. Increased rate of trade, transport and people movement facilitates accidental as well as intentional entry of plant specimens, seeds or propagules of invasive plants into the country.

It is popularly known that alien plant species invasion in tropical forests is largely induced by human disturbance and that undisturbed tropical forests tend to have few alien species (Fine 2002). A study in tropical rainforests of the Western Ghats in India reports that *Chromolaena odorata* and *Lantana camara* had invaded the understorey and *Maesopsis eminii*, a common tree used as shade tree in coffee plantations has invaded species substantial areas of Anamalai Hills of Western Ghats (Joshi *et al.*, 2015).

Prosopis juliflora

Of the many negative ecological impacts known of *Prosopis juliflora*, some of the noted studies were done by Kaur *et al.*, 2012 and Chandrasekharan *et al.*, 2014. Central Arid Zone Research Institute (CAZRI), Jodhpur has conducted considerable research on invasion, biomass productivity and other aspects in the western India. Arid Forest Research Institute, Jodhpur has reported on the impact of *Prosopis* invasion on diversity and productivity of herbaceous vegetation (Singh 2012). In the Peninsular India, there is a growing concern among the people of Tamil Nadu that the *Prosopis* invasion leads to reduction in rainfall, depletion of ground water, reduction in soil moisture, increase in temperature, change in humidity and reduction in grass cover. However, there is lack of data on the impact of *Prosopis* invasion on Humidity, temperature and soil moisture.

Mikania micrantha

Mikania micrantha has reported to be invaded in many of the forest areas of Assam and in some areas its infestation is extremely severe particularly in semi-evergreen forests. It has been found to cover degraded and disturbed sites of Assam and is one of the major threats to the indigenous biodiversity of various protected areas like Kaziranga National Park, Manas National Park, Orang National Park, Pabitora Wildlife Sanctuary (Vattakkavan *et al.*, 2002, Lahkar *et al.*, 2011, Rahmani, *et al.*, 2016), Dilli Reserve forest, Abhyapur Reserve Forest, Bherjan-Borajan-Padumoni Wildlife Sanctuary, Bornadi-Khalingduar Complex of Assam etc. In many areas of north east India it has been reported to alter the natural forests ecosystem. Recently Rain Forest Research Institute, Jorhat has concluded a study on assessing the impact of *M. micrantha* on Semi-evergreen forest ecosystem of upper Assam. The results of this study revealed that soil quality, mainly soil moisture and pH, decreased drastically in Mikania infested areas. The regeneration of native species like *Dipterocarpus retusus, Mesua ferrea, Terminalia myriocarpa, Artocarpus chaplasha etc.* has been found to be affected due to *M. micrantha*.

Lantana camara

There are many studies which have shown its negative impacts on ecosystem and biodiversity which include *L. camara's* potential to change the floral and structural composition of native communities and adult tree mortality (Sharma *et al.*, 2005; Sahu and Singh, 2008; Dogra *et al.*, 2009; Dobhal *et al.*, 2011; Sharma and Raghubanshi, 2011; Sundaram and Hiremath 2012). Its invasion leads to poor productivity, reduction in species richness and disturbs regeneration process by decreasing germination (Sharma *et al.*, 1988; Sharma *et al.*, 2005). It affects the structure of the bird community as well as butterflies activities (Aravind *et al.*, 2010; Jambhekar and Isvaran, 2016). However there are limited studies that focus on impact of invasion on other fauna. The species is also known to cause destructive wildfire in various regions of India. Biological control by introduction of natural enemies is one of the options used in some countries (Messing and Wright 2006). A study by Singh *et al*. (2018) has identified three species to out compete invasive species and it has been found effective in controlling the spread of *L. camara.* The study concludes that, by artificially increasing the density of identified native species (through artificial propagation) coupled with mechanical removal of *L. camara* will not only eradicate the invasive species from the area, but will also prevent further invasion.

Acacia mearnsii

A. mearnsii is recorded as being highly competitive and eventually reducing the presence of native and/or indigenous vegetation (De Wit, 2001). The invasiveness of this species is partly due to its ability to produce large amounts of long-lived seeds. Its leaves and branches have allelopathic properties. The large quantities of litter deposited by this tree and its nitrogen fixation lead to increases in soil nitrogen and changes in nutrient cycling patterns. Karunakaran *et al.* (1998) studied the effects of black wattle *(Acacia mearnsii)* plantations on the montane grasslands and found that older plantations within the grasslands contained fewer endemic species and more weedy species compared to more recent plantations.

IMPACT OF INVASIVE SPECIES ON PROTECTED AREAS AND WILDLIFE

India's 668 protected areas account for about 4.9 % of the country's geographic area (Krishnan *et al.*, 2012). According to Indian Wildlife Protection Act protected areas consist of Wildlife Sanctuaries, National Parks, conservation reserves, and community conserved areas varying in the degree of human use permitted within them. There is already a growing literature available on the negative impacts of invasive plants on native species, wildlife habitats, disturbance regimes, and ecosystem services worldwide (Simberloff *et al.*, 2013; Foxcroft *et al.*, 2014). Despite, little attention has been paid towards these species until recently in Indian PAs. A study of *L. camara* in Biligiri Rangaswamy Temple Tiger Reserve (BRT) constitutes perhaps the first systematic, long-term monitoring record of an invasive species spread in a PA in India (Sundaram and Hiremath, 2012). Another invasive species known as *Prosopis juliflora* was introduced to several PAs like Keoladeo National Park (Anoop, 2010) Ranthambore (Dayal, 2007) and Kumbalgarh (Robbins, 2001) in the desert state of Rajasthan in Northwest India to meet the needs of fuel wood demand which further became problematic in these protected areas. In the Banni grassland which is a part of Kutch, the rate of *P. juliflora's* spread was recorded using remote sensing to be as much as 25.5 km^2 per year (Tewari *et al.*, 2000). Studies have documented its impacts on native vegetation and forest-dependent communities in and around Kumbhalgarh Wildlife Sanctuary as well where its invasion is accompanied by other unpalatable shrubby species including *L. camara* has led to the exclusion of important fodder grasses (Robbins, 2001). It is also causing indigestion and tooth decay in animals inside the Sathyamangalam Tiger Reserve. Spread of *P. juliflora* have lead to the replacement of many native species like *Acacia nilotica, Mitragyna parvifolia, Prosopis cineraria, Salvadora oleoides, Salvadora persica* and *Ziziphus mauritiana* in Keoladeo National Park (Mukherjee *et al.*, 2017). However the impacts of *P. juliflora* in PAs have not been as well documented as those of *L. camara.* Research on invasive plant species in Indian Protected Areas is very limited and there is a need for other invasive species studies in Indian PAs beside *Lantana camara* and *Prosopis juliflora* for proper management and conservation of the protected areas around the country. Selected invasive alien plant speceis invasion in some of the protected areas are given in Plates 4 and 5.

ROLE OF INVASIVE SPECIES IN AVIAN BIODIVERSITY LOSS

Invasive plants are becoming threat to avian diversity as well. These species expose them into new areas which are unsuitable for them and may change local bird assemblage pattern, prey-predator interaction, nesting season or increase the rate of nest predation. At Vettangudi Bird Sanctuary, South India invasive tree Prosopis juliflora contributed significant threat to the nesting success of wetland birds (Chandrasekaran *et al.*, 2014). However specific reason for the low nesting success in *P. juliflora* still needs further research. Invasion of *P. juliflora* has shown to replace natural habitat in India's premier bird reserve, the Keoladeo National Park (Anoop, 2010). Similarly at moist and dry deciduous forests in Malé Madeshwara Hills, Karnataka, *Lantana* invasion in both the forest type affects the structure of the bird community by decreasing bird species diversity, species richness and abundance. In India there are limited studies addressing the detailed impacts of invasive plant species on birds and other fauna. Therefore more research is needed in this direction so as to prevent the loss of bird diversity due to invasive plants.

Invasion of *Eichornia Crassipes* and *Mimosa Diplotricha*

Pontederia crassipes (Eichhornia crassipes) invasion in Kaziranga National park, Assam

Mimosa diplotricha invasion in Kaziranga National park, Assam

(Photo source: Dr. Dhruba J. Das, RFRI, Jorhat)

Invasion of *Mikania micrantha*

Mikania micrantha invasion

(Photo source: Dr. K. N. Baruah, RFRI, Jorhat)

INVASIVE SPECIES - LEADING CAUSE FOR HUMAN-WILDLIFE CONFLICT

Beside the loss of native biodiversity invasive species have become one of the major threats to wildlife conservation globally and is considered one of the reasons for the increase in conflict between human and wildlife in India. In Nilgiris it has been reported that spread of invasive plant species forced the wild animals to move out of forests into fields and farms in search of food because of the reduced native food plants leading to human-wildlife conflict. Their establishment have become problematic in terms of native food plant cover and reduced habitat for species like rhino and elephant in National parks like Kaziranga and Orang in Assam (Lahkar *et al.*, 2011) and Mudumalai Tiger Reserve (Kaushik and Mungi, 2015). The spread of invasive species in grassland habitats have led to reduction of suitable flora for rhinos and other herbivores in India and Nepal which has become a major concern in recent years. The leading invasive species in rhino habitats in India include *Mikania micrantha, Mimosa* spp., *Ipomoea* spp. and *Chromolaena odorata* (Lahkar *et al.*, 2011). Invasion of Mimosa has emerged as a major threat in Kaziranga National Park (NP) in Assam (Vattakkavan *et al.*, 2002).

INVASIVE SPECIES ALTERS LIVELIHOOD

Invasive species have been reported to have both positive and negative impacts on human activities (Binggeli *et al.*, 1998). In tropics, grasslands are invaded by introduced woody plants and reduce the livestock carrying capacity of these grasslands and sometimes make livestock farming uneconomic *(eg. Acacia nilotica, Mimosa pigra, Lantana camara)*. Like in India, thickets of *Prosopis juliflora* harbour many bee hives and nearby villagers extract the honey. Many invasive species are also visited by bees and they are claimed to be of value to bee-keepers but their importance has yet to be demonstrated. Some species are clearly unsafe sources of nectar or pollen as they may kill the bees or the resulting honey may be more or less toxic to humans as in the case of *Nerium oleander*. A study conducted in forest-dwelling Soliga community of South India, their views explains biological invasions (Sundaram *et al.*, 2012). The Soliga believe that lantana invasion has had negative effects on the ecosystem and their livelihoods. They observed that fires are uniformly detrimental and promote lantana (Sundaram *et al.*, 2012).

POSITIVE ASPECTS OF INVASIVE SPECIES

Invasive plants are not only known for their negative impacts but they also have some positive attributes to play that can be a boon to the environment in different ways. In Dry deciduous forests of India habitats with large Lantana cover have high concentrations of organic carbon and total nitrogen in the soil of invaded areas (Sharma and Raghubanshi, 2011). Invasion by *Ageratum conyzoides* in Shivalik hills of Himachal Pradesh also resulted in increase in soil nutrients (Dogra *et al.*, 2009). Invasive plants have potential for carbon sequestration which is an emerging area that needs to be further explored. The increase in carbon emission is a major issue which is also addressed in Kyoto Protocol (Ravindranath *et al.*, 1997). Therefore due to their abundance and wide spread distribution, ability to out compete other species, high rate of survival they may store more carbon which will further help in the mitigating the harmful effects of climate change. *Prosopis juliflora* can help in sequestering atmospheric carbon dioxide and site restoration activities (Pandey *et al.*, 2016; Pandey *et al.*, 2015). Patel *et al.*, (2017) study recorded the highest Carbon content as well as Carbon dioxide sequestration under *Prosopis juliflora* tree species as compared to the other trees like *Azadirachta indica, Prosopis cineraria, Acacia tortolis* in Sardarkrushinagar, Gujarat. It can also be considered for developing greenbelts and as air purifiers in case where the land involved is not rich enough to support other trees (Saxena *et al.*, 2011). In addition invasive species can also be an important source of food for birds. Recent study of Aruna and Balasubramanian, (2017) have found a total 11 species of birds that were feeding on the ripe fruits of invasive weed *L. camara* in a mixed dry deciduous forest, Anaikatty hills, Western Ghats. According to their observations bulbuls and mynas were the predominant seed dispersers of *L. camara*. Brightly coloured flowers of invasive plant *P. juliflora* can serve as a source of pollen and nectar which helps to attract native pollinators (Patnaik *et al.*, 2017). However, this may result in negative effect also in terms of further spread of invasive plant species into the environment which can have detrimental effect on other native vegetation in particular area.

Some invasive species are known for accumulating heavy metals from the soil which can be helpful in phytoremediation of polluted environments. *Lantana camara* and *Wedelia trilobata* have potential to selectively remove ions of heavy metals, Lantana can remove ions like Zn^{+2}, Co^{+2},Cd^{+2},Ni^{+2} and Mn^{+2} up to some extent (Dissanayake *et al.*, 2002). Also, *Prosopis juliflora* have potential to purify heavy metals like Cu, Pb and Cd contaminated soils (Senthilkumar *et al.*, 2005; Varun *et al.*, 2011). Chinmayee *et al.*, (2012) assessed phytoremediation potential of invasive weed *Amaranthus spinosus* L. for its potential to accumulate heavy metals. Such potential of invasive plants can help to minimize their spread in habitats which are near industries or where there is effluent discharge taking place.

FUTURE IMPLICATIONS

Finally, it is high time to incorporate Invasive plant management into land use planning. Governments are responsible for land use planning, which ensures that natural heritage features and resources are considered in community development. It also helps to plan for the incorporation of goals such as an increase in urban forests, a reduction in sprawl and more local jobs, to name a few. One specific example is the loss of forest cover and the fragmentation of forests, which can contribute to, and promote the spread of invasive plants. Land use planning that considers the impacts of the loss of cover and tries to mitigate the effects, will be more successful in preventing the spread of invasive plants.

Global changes, such as major population shifts, expanding international tourism and commerce, deforestation, and water development projects, could increase the likelihood of future introductions of invasive species. In order to be better prepared for such situations, better surveillance systems should be developed. Surveillance for conditions that may foster alien species introductions requires a multi-disciplinary approach involving professionals from many fields of biology, ecology, and climatology, in addition to medicine and public health. These professionals should take advantage of multiple opportunities for scientific exchange and cooperation to address the threats presented by alien species introductions to biodiversity and to human health.

REFERENCES

Anoop, K.R. (2010). Progress of *Prosopis juliflora* eradication work in Keoladeo National Park.

Aravind, N.A., Rao, D., Ganeshaiah, K.N., Shaanker, R.U. and Poulsen, J.G. (2010). Impact of the invasive plant, *Lantana camara*, on bird assemblages at Male Mahadeshwara Reserve Forest, South India, Tropical Ecology, 51: 325-338.

Aruna, R. and Balasubramanian, P. (2017). Fruiting phenology and avian frugivory on *Lantana camara* in a mixed dry deciduous forest, Western Ghats, Tamilnadu, India, International Journal of Fauna and Biological Studies, 4(4): 179-182.

Ashton, W. and Rempel, K. (2010). Economic Impact Assessment of Leafy Spurge in Southern Maniboba - Final Report. 43pp.

Bhatt, J. R., Singh, J. S., Singh, S. P., Tripathi, R. S., and Kohli, R. K. (2011). Invasive alien plants an ecological appraisal for the Indian Subcontinent, (Vol. 1), Cabi.

Bhatt, J.R., Singh, J.S., Singh, S.P., Tripathi, R.S. and Kohli, R.K. (Ed.). (2012). Invasive Alien Plants: An ecological appraisal for the Indian Sub Continent (Vol. 1), CABI, UK.

Binggeli, P., Hall, J.B. and Healey, J.R. (1998). An overview of invasive woody plants in the tropics.

Chandrasekaran, S., Saraswathy, K., Saravanan, S. N., Kamaladhasan N. and Arunnagendran. (2014). Impact of *Prosopis juliflora* on nesting success of breeding wetland birds at Vettangudi Bird Sanctuary, South India. Current science, 106(5): 676-678.

Chellamuthu, V., Balasusbramanian, T.N., Rajarajan, A. and Palaniappan, S.N.(1977). Allelopathic influence of *Prosopis juliflora* on field crops. Allelopathy Journal, 4(2): 291-302.

Chinmayee, M.D., Mahesh, B. and Pradesh, S. (2012). The assessment of phytoremediation potential of invasive weed *Amaranthus spinosus* L., Applied Biochemistry and Biotechnology, 167, 550.

Dayal, V. (2007). Social diversity and ecological complexity: how an invasive tree could affect diverse agents in the land of the tiger. Environment and Development Economics, 12: 1-19.

De Wit, M.P., Crookes, D.J. and Van Wilgen, B.W. (2001). Conflicts of interest in environmental management: Estimating the costs and benefits of a tree invasion, Biological invasions, 3(2): 67-178.

D'hondt, B., Vanderhoeven, S., Roelandt, S., Mayer, F., Versteirt, V., Adriaens, T., Ducheyne, E., San Martin, G., Grégoire, J.-C., Stiers, I., Quoilin, S., Cigar, J., Heughebaert, A. and Branquart, E. (2015).Harmonia + and Pandora +: risk screening tools for potentially invasive plants, animals and their pathogens, Biological Invasions, 17: 1869-1883.

Díaz, S., Fargione, J., Chapin III, F.S. and Tilman, D. (2006). Biodiversity loss threatens human well-being. PLoS biology, 4(8): 277.

Dissanayake, U.S., Tennakoon, K. U. and Priyantha, N. (2002). Potential of two invasive plant species, *Lantana camara* L. and *Wedelia trilobata* L., for selective heavy metal uptake. Ceylon Journal of Science (Biological Science), 29: 1-11.

Dobhal, P. K., Kohli, R. K. and Batish, D. R. (2010). Impact of *Lantana camara* L. invasion on riparian vegetation of Nayar region in Garhwal Himalayas (Uttarakhand, India), Journal of Ecology and the Natural Environment, 3(1): 11-22.

Dobhal, P.K., Kohli, R.K. and Batish, D.R. (2011). Impact of *Lantana camara* L. invasion on riparian vegetation of Nayar region in Garhwal Himalayas (Uttarakhand, India), Journal of Ecology and the Natural Environment, 3(1):11-22.

DOEF, (2010). Assam's Rich Biodiversity, Department of Environment and Forests, Government of Assam.

Dogra, K.S. (2008). Impact of some invasive species on the structure and composition of natural vegetation of Himachal Pradesh, PhD thesis, Punjab University, Chandigarh, India.

Dogra, K.S., Kohli, R.K. and Sood, S.K. (2009). An assessment and impact of three invasive species in the Shivalik hills of Himachal Pradesh, India, International Journal of Biodiversity and Conservation, 1(1): 4-10.

Dukes, J.S. and Mooney, H.A. (2004). Disruption of ecosystem processes in western North America by invasive species, Revista Chilena de Historia Natural, 77: 411-437.

Ehrenfeld, J.G. (2010). Ecosystem consequences of biological invasions, Annu. Rev.Ecol. Evol. Syst., 41, 59-80.

Ekta. (2014).Dominance of *Prosopis juliflora* (Sw.) DC. in the Delhi ridge forest of the semi-arid region, India. The Biobrio, 1 (1): 41-44.

Fine, P.V.A. (2002).The invasibility of tropical forests by exotic plants, Journal of Tropical Ecology, 18:687–705.

Foxcroft, L.C., Pys?ek, P., and Richardson, D.M.et al. (2014).Impacts of alien plant invasions in protected areas. In: Plant invasions in protected areas: patterns, problems and challenges (Foxcroft, L.C., Pys?ek, P., Richardson, D.M., Genovesi, P. Eds), Springer, Dordrecht, 19-41.

Frid, L., D. Knowler, C. Murray, J. Myers, and L. Scott. (2009). Economic Impacts of Invasive Plants in BC. Prepared for the invasive plant council of BC by ESSA technologies Ltd., Vancouver, BC. 107 pp.

Gaertner, M., Breeyen, A.D., Hui, C. and Richardson, D.M. (2009). Impacts of alien plant invasions on species richness in Mediterranean-type ecosystems: a meta-analysis, Progr. Phys. Geogr., 33: 319-338.

Gantayet, P.K., Adhikary, S.P., Lenka, K.C. and Padhy, B. (2014). Allelopathic impact of *Lantana camara* on vegetative growth and yield components of green gram *(Phaseolus radiatus)*. International Journal of Current Microbiology and Applied Science, 3(7): 327-335.

Hejda, M., Pys?ek, P. and Jaros?ìk, V. (2009). Impact of invasive plants on the species richness, diversity and composition of invaded communities. J. Ecol., 97: 393-403.

Inderjit and Callaway, R.M. (2003). Experimental designs for the study of allelopathy, Plant and Soil, 256:1-11.

Inderjit and Duke, S. O. (2003). Ecophysiological aspects of allelopathy. Planta, 217: 529-539.

Jambhekar, R.M. and Isvaran, K. (2016). Impact of the invasive weed *Lantana camara* (Verbenaceae) on butterfly behaviour and habitat use in a tropical forest in India, The Journal of the Lepidopterists' Society, 70(4): 302-310.

Joshi, A. A., Mudappa, D. and Shankar Raman, T. R. (2015). Invasive alien species in relation to edges and forest structure in tropical rainforest fragment of the Western Ghats, Tropical Ecology, 56(2): 233-244.

Kanchan, S.D. and Jayachandra. (1980). Allelopathic effects of *Parthenium hysterophorus* L. IV. Identification of inhibitors. Plant and Soil, 55: 67-75.

Karunakaran, P. V., Uniyal, V. K., and Rawat, G. S. (1998). Ecology and conservation of the grasslands of Eravikulam National Park, Western Ghats. Wildlife Institute of India.

Katsanevakis, S., Wallentinus, I., Zenetos, A., Leppäkoski, E., Çinar, M.E., Oztürk, B., Grabowski, M., Golani, D. and Cardoso, A.C. (2014). Impacts of invasive alien marine species on ecosystem services and biodiversity: a pan-European review, Aquatic Invasions, 9(4): 391-423.

Kaur, R., Gonzales, W. L., Llambi, L. D., Soriano, P. J., Callaway, R. M., Rout, M. E., *et al.* (2012). Community impacts of *Prosopis juliflora* invasion: Biogeographic and congeneric comparisons, PLOS One, 7(9): e44966.

Kaur, R., Malhotra, S. and Inderjit. (2012). Effects of invasion of *Mikania micrantha* on germination of rice seedlings, plant richness, chemical properties and respiration of soil Biology and Fertility of Soils, 48(4): 481.

Kaushik, M. and Mungi, N. (2015). Human-wildlife interactions and management of invasive alien species, Current Science, 108: 1039-1040.

Kohli, R. K., Dogra, K. S., Batish, D. R., and Singh, H. P. (2004). Impact of invasive plants on the structure and composition of natural vegetation of northwestern Indian Himalayas, Weed Technology, 18 (sp1): 1296-1300.

Kohli, R.K., Jose, S., Singh, H.P. and Batish, D.R. (2009). Invasive Plants and Forest Ecosystems, CRC Press, Boca Raton, Florida, 437.

Krishnan, P., Ramakrishnan, R., Saigal, S. (2012). Conservation across landscapes: India's approaches to biodiversity governance, United Nations Development Programme, New Delhi.

Lahkar, B.P, Talukdar, B.K. and Sarma, P. (2011). Invasive species in grassland habitat: an ecological threat to the greater one-horned rhino *(Rhinoceros unicornis)*, 49:33-39.

Levine, J.M., Vila`, M., D? Antonio, C.M., Dukes, J.S., Grigulis, K. and Lavorel, S.(2003). Mechanisms underlying the impact of exotic plant invasions, Proc. R. Soc. London, Series B, 270: 775-781.

Liao, C., Peng, R., Luo, Y., Zhou, X., Wu, X., Fang, C. et al. (2008). Altered ecosystem carbon and nitrogen cycles by plant invasion: a meta-analysis, New Phytol., 177: 706-714.

Mangla, S., Inderjit, and Callaway, R. M. (2008). Exotic invasive plant accumulates native soil pathogens which inhibit native plants, Journal of Ecology, 96: 58-67.

Messing, R. H. and Wright, M. G. (2006). Biological control of invasive species: solution or pollution?, Front Ecol Environ, 4(3): 132-140.

Mukherjee, A., Velankar, A. D. and Kumara, H. N. (2017). Invasive *Prosopis juliflora* replacing the native floral community over three decades: a case study of a World Heritage Site, Keoladeo National Park, India, Biodiversity and Conservation, 26 (12): 2839-2856.

Naudiyal, N., Schmerbeck, J. and Gärtner, S. (2017). What influences the plant community composition on Delhi ridge? The role played by *Prosopis juliflora* and anthropogenic disturbances, Tropical Ecology, 58: 33-43.

Pandey, V. C., Prakash, P., Bajpai, O., Kumar, A. and Singh, N. (2015). Phytodiversity on fly ash deposits: evaluation of naturally colonized species for sustainable phytorestoration, Environmental Science and Pollution Research, 22: 2776-2787.

Pandey, V. C., Sahu, N., Behera, S. K. and Singh, N. (2016). Carbon sequestration in fly ash dumps: comparative assessment of three plant association, Ecological Engineering, 95: 198-205.

Pasiecznik, N., Felker, P., Harris, P., Harsh, L. and Cruz, G., et al. (2001). The *Prosopis juliflora – Prosopis pallida* complex: A monograph, HDRA, Coventry, UK. 172 p.

Patel, K.N., Shakhela, R.R. and Jat, J.R. (2017). Growth, Biomass Production and CO_2 Sequestration of Some Important Multipurpose Trees under Rain fed Condition. International Journal of Current Microbiology and Applied Science, 6(10): 1943-1950.

Patnaik, P., Abbasi, T. and Abbasi, S. A. (2017). Prosopis *(Prosopis juliflora)*: blessing and bane. Tropical Ecology, 58(3): 455-483.

Pejchar, L. and Mooney, H.A. (2009). Invasive species, ecosystem services and human well-being, Trends Ecol. Evol., 24: 497-504.

Perrings, C., Williamson, M., Barbier, E., Delfino, D., Dalmazzone, S., Shogren, J., Simmons, P., and Watkinson, A. (2002). Biological invasion risks and the public good: An economic perspective. Conservation Ecology 6(1): 1.

Pimentel, D., McNair, S., Janecka, J., Wightman, J., Simmonds, C., O'Connell, C., Wong, E., Russel, L., Zern, J., Aquino, T. and Tsomondo, T. (2001). Economic and environmental threats of alien plant, animal, and microbe invasions, Agriculture, Ecosystems and Environment, 84: 1-20.

Pimentel, D., Zuniga, R., and Morrison, D. (2005). Update on the environmental and economic costs associated with alien-invasive species in the United States, Ecological Economics, 52: 273-288.

Powell, K.I., Chase, J.M. and Knight, T.M. (2011). A synthesis of plant invasion effects on biodiversity across spatial scales. Am. J. Bot., 98: 539-548.

Raghubanshi, A.S., Rai, L.C., Gaur, J.P. and Singh, J.S. (2005). Invasive alien species and biodiversity in India, Current Science, 88(4): 539-540.

Rahmani, A., Zafar-ul, I and Kasambe, R. (2016). Important Bird and Biodiversity Areas in India Priority sites for conservation.

Rana, J.C., Singh, A., Sharma, Y., Pradheep, K. and Mendiratta, N. (2010).Dynamics of plant bioresources in Western Himalayan region of India-watershed based study. Current Science, 98: 92-203.

Ravindranath, N.H., Somashekhar, B.S., and Gadgil, M. (1997).Carbon flow in Indian forests, Climate Change, 35: 297-320.

Rawat, G.S., Goyal, S.P. and Johnsingh, A.J.T. (1997). Ecological observations on the grasslands of Corbett Tiger Reserve, India, Indian Forester, 123: 958-963.

Reddy, C.S. and Pattanaik, C. (2009). An assessment of floristic diversity of Gandhamardan Hill range, Orissa, India, Bangladesh Journal of Plant Taxonomy, 16: 29-36.

Rice, E.L. (1984). Allelopathy, 2nd edition. Academic Press, New York, USA.

Robbins, P. (2001). Tracking invasive land covers in India, or why our landscapes have never been modern, Annals of the American Association of Geographers, 91: 637-659.

Sahu, P.K. and Singh, J.S. (2008). Structural attributes of lantana-invaded forest plots in Achanakmar-Amarkantak Biosphere Reserve, Central India, Current Science, 494-500.

Saxena, P., Bhardwaj, R. and Ghosh, C. (2011). A sustainable way to control air pollutants with the use of plant species at selected areas in Delhi, Fresenius Environmental Bulletin, 20(10A): 2662-2669.

Senthilkumar, P., Prince, W. S. P. M., Sivakumar, S. and Subbhuraam, C.V. (2005). *Prosopis juliflora* - A green solution to decontaminate heavy metal (Cu and Cd) contaminated soils, Chemosphere, 60: 1493-6.

Sharma, G. P., Raghubanshi, A. S., and Singh, J. S. (2005). Lantana invasion: an overview. *Weed Biology* and *Management*, 5(4), 157-165.

Sharma, G.P. and Raghubanshi, A.S. (2006). Tree population structure, regeneration and expected future composition at different levels of *Lantana camara* L. invasion in the Vindhyan tropical dry deciduous forest of India, Lyonia, 11: 25-37.

Sharma, G.P., and Raghubanshi, A.S. (2011). Invasion and impact on herb layer diversity and soil properties in a dry deciduous forest of India, Applied Ecology and Environmental Research, 9(3): 253-264.

Sharma, O.P. (1988). How to combat Lantana (*Lantana camara* L.) menace- A current perspective, Journal of Scientific and Industrial Research, 47: 611-616.

Sharma, O.P., Makkar, H.P.S. and Dawra, R.K. (1988). A review of the noxious plant *Lantana camara*, Toxicon, 26: 975-987.

Sharma, R. and Dakshini, K.M.M. (1998). Integration of plant and soil characteristics and the ecological success of two Prosopis species, Plant Ecology, 139: 63-69.

Siddiqui, S., Bhardwaj, S., Khan, S.S. and Meghvanshi, M. K. (2009). Allelopathic effect of different concentration of water extract of *Prosopsis juliflora* leaf on seed germination and radicle length of wheat (*Triticum aestivum* Var-Lok-1), American-Eurasian Journal of Scientific Research, 4 (2): 81-84.

Silori, C.S. and Mishra, B.K. (2001). Assessment of livestock grazing pressure in and around the elephant corridors in Mudumalai Wildlife Sanctuary, south India, Biodiversity and Conservation, 10: 2181-2195.

Simberloff, D., Martin, J.L. and Genovesi, P. (2013). Impacts of biological invasions: what's what and the way forward? Trends in Ecology and Evolution, 28: 58-66.

Singh, I. (2012).Control of lantana and restoration of biodiversity in reserve forests of Chandigarh: a case study, CAB International. Invasive alien plants: An ecological appraisal for the Indian subcontinent (eds J.R. Bhatt et al.)

Singh, S., Khatri, P. K., Kumar, D. and Naik, V. R. (2018). Biological-control of *Lantana camara* through crop competition using native species, Indian Journal of Tropical Biodiversity, 26 (1): 81-86.

Sundaram, B. and Hiremath, A.J. (2012). *Lantana camara* invasion in a heterogeneous landscape: patterns of spread and correlation with changes in native vegetation, Biological Invasions, 14: 1127-1141.

Sundaram, B., Krishnan, S., Hiremath, A.J. and Joseph, G. (2012). Ecology and impacts of the invasive species, *Lantana camara*, in a social-ecological system in South India: perspectives from local knowledge, Human Ecology, 40(6): 931-942.

Swamy, P.S., Sundarapandian, S.M., Chandrasekar, P. and Chandrasekaran, S. (2000).Plant species diversity and tree population structure of a humid tropical forest in Tamil Nadu, India. Biodiversity and Conservation, 9: 1643-1669.

Tewari, J.C, Harris, P.J.C., Harsh, L.N., Ladoret, K. and Pasiecznik, N.M. (2000). Managing *Prosopis juliflora* (Vilayati babul): A technical manual, CAZRI, Jodhpur, India and HDRA Conventry, UK, 96.

Varun, M., D'Souza, R. and Pratas, J. (2011). Phytoextraction Potential of *Prosopis juliflora* (Sw.) DC. with specific reference to lead and cadmium. Bulletin of Environmental Contamination and Toxicology, 87: 45.

Vattakkavan, J., Vasu, N.K., Varma, S., Gureja N. and Aiyadurai, A. (2002). 'Silent stranglers: Eradication of Mimosa in Kaziranga National Park, Assam', Wildlife Trust of India, New Delhi, 55.

Vila`, M. and Weiner, J. (2004). Are invasive plant species better competitors than native plant species? Evidence from pair-wise experiments, Oikos, 105: 229-238.

Vila`, M., Tessier, M., Suehs, C.M., Brundu, G., Carta, L. and Galanidis, A. (2006). Local and regional assessment of the impacts of plant invaders on vegetation structure and soil properties of Mediterranean islands, J. Biogeogr., 33: 853-861.

Websites: Conservation Tools; *https://conservationtools.org*

Zavaleta, E. (2000). Invasive species in a changing world, Valuing ecosystem services lost to Tamarix invasion in the United States, 261-300.

5 INVASIVE INSECT SPECIES IN FORESTS OF INDIA AND THEIR MANAGEMENT

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INVASIVE ALIEN SPECIES

An invasive species is a plant or animal that is, by origin, alien to the local ecosystem. The species grows or reproduces at a speed generally faster than indigenous species. Gradually, this species may become a dominant species and cause economic and ecological stress. Invasions can occur through two sources - external or internal. Wherever humans have travelled, they have transported other animal and plant species with them. These may be as domesticated animals or plants, or of wild origin. Often these species have been deliberately released. Some of these introduced species become independently established over time, and start invading the habitats of other species.

Invasive Alien Species (IAS) are found in all taxonomic groups including introduced viruses, fungi, algae, mosses, ferns, higher plants, invertebrates, fishes, amphibians, reptiles, birds, and mammals (ISSG 2015). Although insects form a large part of the alien fauna worldwide, invasive alien insects appear to have received disproportionately less attention. Alien insects can affect native biodiversity through direct interactions and also indirectly through cascading effects. Invasive insect pollinators, in addition to causing hazards through hybridization, may also compete with native pollinators for floral resources and nesting sites. There are clear and important gaps in our knowledge of the effect of alien insects on native biodiversity and ecosystems (ISSG 2015).

India is considered to be one of the 12 mega-biodiversity countries of the world. It has two important biodiversity hotspots, out of 18 in the world, located in the south and northeast parts of the country. India has nearly 70 million hectares of forests, which is nearly 24.1 per cent of the geological area of the country (FSI). Unfortunately, some of these vital natural resources are under threat due to invasions by exotic or alien species. During the last decades Invasive Alien Species (IAS) has been identified as the major factor directly affecting India's natural resource, placing constraints on the protection of watershed and native flora and fauna. The invasive alien taxa causing the most damage in India include insects, plants and pathogens. Though there is no accurate estimation of the ecological and economic loss due to direct as well as associated effects of invasive alien species, the rough figures across nations is quite alarming.

Over the past few decades there has been a steady expansion of forest plantations across the country. Plantations are now regarded as a means to meet the wood requirement of the nation without putting so much pressure on the shrinking natural forest in the country. Raising the plantation in forestry marked the beginning of serious pest problems. Insect species, which remained innocuous in natural forests, started multiplying in plantations causing epidemic outbreaks and enormous damage. Problem of drying of chir pine in Shiwalik range of Himalayas has become a chronic problem and sal forest suffers from the invasion of sal borers. There are about 500 species of insect known to damage forests and forest products in the Himalayas. There is no doubt that newly introduced alien pest species can be devastating, particularly to plantation forestry (Nair, 2001) and to the biodiversity associated with forests. In future, increasing numbers of accidental introductions can be expected more as a result of the growing internationalization of trade, the increasing movement of people, and the consequent overwhelming of quarantine services. It is not easy to predict which alien species are likely to cause serious damage if introduced. Many species are innocuous or minor pests in their area of origin, but can be devastating elsewhere. For example, of six of the most devastating forestry pests introduced into India (including chestnut blight, Dutch elm disease, etc.), only the European strain of the gypsy moth was known as a pest in its indigenous range.

RESEARCH STATUS OF INVASIVE INSECTS IN FORESTS

There are a number of invasive forest insect species that cause problems in India. The invasiveness of insects is governed by many features. Success or failure of introduced insect outbreak densities depends on climatic differences between native and exotic areas; quantity of food or taxonomic differences in host plants between exotic and native areas; predators and parasitoids in exotic areas; reduced genetic variability in the introduced population and competition with native insects. There are several cases of invasion of indigenous insect pests on indigenous tree crops in forest plantations, for example *Ectropis deodare*, a major defoliator pest of deodar. There are periodic outbreaks of this pest in all age classes of deodar forest. Many pest issues, which earlier were considered to be minor, have attained pest status in India owing to intensive management practices and climatic factors, especially for Conifer forests (Singh *et al.*, 2009). Also, new and emerging pests have been attributed to agrosilvicultural practices. For example, *Thysanoplusia orichalcea*, which is known to be a notorious agricultural pest, was found to feed on the crops of higher altitude range like *Saussurea costus* in Himachal Pradesh.

Similarly, the invasion of *Heteropsylla cubana* on subabul; *Leptocybe invasa* on Eucalyptus; *Pineus laevis* on *Pinus patula; Icerya purchasi* on *Acacia* sp; *Quadraspidiotus perniciosus* on poplars and willows *Orthezia insignis* on Lantana, *Aleurodicus disperses* on Cassia, *Paracoccus marginatus* on Jatropha, *Quadrastichus erythrinae* on Erythrina spp, and *Lymantria obfuscata* on *Quercus* sp. were reported in India.

TYPES OF INVASIVE INSECTS IN FOREST TREES

Exotic Insects on Exotic Tree Species

The classical example of an exotic insect invasion on an introduced tree species in India is that of *Heteropsylla cubana* (Homoptera: Psylidae) invading subabul *(Leucaena leucocephala)*. The insect was first reported in Chengalpet (Tamil Nadu), South India, in 1988. By 1990, it had attacked all the *Leucaena* plantations in the country.

Leptocybe invasa (Hymenoptera: Eulophidae) native to Queensland, Australia, was Ist reported from Israel as pest of Eucalyptus in 2000 and has subsequently spread very quickly by flight and wind currents to new areas in the Mediterranean basin, Africa, Asia and Europe including India. It has a narrow host range attacking Eucalyptus species. Gall formation by this chalcid wasp on leaves of Eucalyptus causes deformation of terminal shoots and results in quicker abscission of leaves and drying up of shoots. Seedlings in nursery and young plantations are particularly susceptible. Ten Eucalyptus spp. were found to be suitable host for this pest; *E. botryoides, E.bridgesiana, E. camaldulensis, E. globulus, E. gunii, E. grandis, E. robusta, E. saligna, E. tereticornis* and *E. viminalis.* Damage in nursery and field to *E. grandis, E. tereticornis* and *E. camaldulensis* were high and recorded to be most susceptible.

Pineus laevis sp. (Homoptera: Adelgidae) was first introduced to India in the 1970s. It has caused severe damage to *Pinus patula* plantations in the Nilgiri hills of South India. The damage has been restricted to *Pinus patula*, because only trial plantations had been established. Its further spread has been contained by discontinuing the planting of *P. patula*.

Icerya purchasi (Homoptera: Coccidae), the cottony cushion scale, was accidentally introduced into India in 1921. It damages *Acacia decurrens* and *A. dealbata* in addition to numerous other forestry and agricultural plant species. The scale has done serious damage to plants in the Nilgiri hills in South India, and in the Anamalai hills in Tamil Nadu, and has since become well established throughout the country.

Exotic Insects on Indigenous Tree Species

Rodolia cardinatis (Coleoptera: Coccinellidae) was introduced for the control of cottony cushion scale, and it has proven to be a very effective predator (Beeson 1941).

Quadraspidiotus perniciosus (Homoptera: Coccidae) or the San Jose scale is a native of China. It reached India in 1911, and by 1933 it had attained pest status in fruit orchards and plantations of poplars and willows. The San Jose scale also damages species of the following genera: *Aesculus, Alnus, Betula, Celtis, Fagus, Fraxinus* and *Morus* (Beeson 1941).

MANAGEMENT OF FOREST PEST INVASIONS

Practically, there has been no research input/ information on the invasive insect species and their economical and ecological impact in this fragile ecosystem. Given the tremendous potential impact of forest invasions and current forest programmes in India, the main theme for tackling this problem is prevention and early detection, backed by Integrated Pest Management programme. This is in line with national development programmes to support the country's sustainable development. The problem of alien invasive species has received considerable attention at all levels of government, with the main emphasis on cooperation between the relevant agencies and international collaboration. The establishment of an efficient early warning and detection programme to actively pursue exclusion - with legal and regulatory support to inspection and quarantine has also been a priority. Extensive monitoring has also been given priority, as it is essential in any programme where the objective is to prevent the establishment of new invaders.

Plant Quarantine

The Government of India took legislative steps in 1914, in order to protect its agricultural and forest species. In that same year, the Directorate of Plant Protection, Quarantine and Storage was established to implement the new regulations. Plant Quarantine and Fumigation Stations were established at major airports, seaports and land frontier check posts across the country.

The most important Acts to control and regulate the export and import of plants, seeds and animals and their products in the country are:

- the Destructive Insects and Pests Act, 1914;
- the Customs Act, 1962; and
- the Foreign Trade (Development and Regulations) Act, 1992.

The Customs Department is the most important organization with regard to the enforcement of Acts relating to international movements of plants, seeds and animals. Customs, in cooperation with the CITES Assistant Management Authorities, the Department of Plant Quarantine and the Department of Animal Quarantine, are the operational organizations that enforce the laws in this regard.

FUTURE STRATEGY TO COMBAT THE MENACE

- Intensive basic research on exotic pests such as good biological information on the pest concerned that can be used to guide decision-making, monitoring and detection techniques needs to be developed. The goal is to build an efficient and broad early warning and detection system to achieve exclusion or early detection leading to the eradication of potential invaders. Legislation and regulatory procedures regarding quarantine, inspection, and intentional introduction of plants or animals need to be strengthened, with more attention to risk assessment before approval and follow-up monitoring after introduction.

- Establishment of forest-pest monitoring and detection centres at county level. These centres can monitor both native and exotic forest pests all year round, to enable early detection.
- Strengthening the coordination and information sharing between the relevant government agencies for forestry, agriculture, trade, and environmental protection and research institutions in dealing with forest invasive species is very important. It is also important to strengthen regional and international cooperation
- It is recognized that public awareness plays a key role in combating invasive species, TV, newspapers, internet and other forms of media are being utilized to inform and educate the general public on the impacts of invasive species.
- The impact of invertebrate pests and plant pathogens is not always obvious or easy to calculate. Just because a pest is present does not mean it has either an immediate or a long-term impact. Furthermore, while the relationships between pests (in the broad sense) and their host plants are relatively well known, the impact of temperate forest pests is relatively poorly documented.
- There are several invasive pest problems common to temperate and tropical forests but at present there is little interaction among researchers both within and between countries. This lack of information sharing often retards progress and leads to avoidable duplication of efforts. Action should be taken to improve communication among different stakeholders.
- Under convention on Biological diversity, the emphasis is to prevent the establishment or spread invasive pest by Global Invasive Species Programme. All the nations must have specific quarantine regulations to restrict the movement of plant material/commodities known to have a risk of exotic pest.

REFERENCES

Beeson, C.F.C. (1941). The Ecology and the control of the forest insect of India and the neighboring countries, Vasant Press, Dehra Dun, Manager of Publ., Government of India, Delhi. 1007.

Nair, K.S.S. (2001). Pest outbreaks in tropical forest plantations: Is there a greater risk for exotic tree species, 74.

Singh, R., Pal, M. and Sharma, R.C. (2009). Forest insect pest and disease management in Northwest Himalayas. ICFRE Number: 128-ICFRE-BK-75/ HFRI-BK-1-2009, Himalayan Forest Research Institute, Shimla: 219 p.

6 BIOLOGICAL CONTROL OF INVASIVE ALIEN SPECIES IN FORESTS OF INDIA

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INTRODUCTION

The negative environmental and health-related effects of the use of pesticides have resulted in a policy shift to reduce the use of those pesticides that are the most harmful. Biological control is one tool that can be utilized to a greater extent to reduce the use of pesticides and still manage high impact invasive species. Today biological control is a 3-way process wherein the host-plant host- insect and the natural enemy are inextricably entangled, the plant producing volatiles to attract insects and their natural enemies besides the volatiles coming from the frass of the host insect which also attract parasites (Ananthakrishnan, 1992). The importance of tritrophic interactions in the biological control of insects, various aspects of biotechnology and increasing dimensions of insect-plant interactions knowledge is essential for successful biological control (Ananthakrishnan, 1992).

What is bio-control?

The most successful method of controlling invasive weeds and pests is biological control, or “biocontrol”, using their own enemies against them. These “biocontrol agents” can be bacteria, fungi, viruses, or parasitic or predatory organisms, such as insects.

Bio-control or biological control is the use of live life forms or creatures, such as insects or pathogens for management of pest populations below the damaging threshold level without causing harm to the other live creatures including humans and the environment. It involves the re-introduction of some of the specialist natural enemies that help control the invasive species it in its native range. The aim of biological control is not to eradicate the invasive species, but control it in a way that the species becomes manageable. In other words, the technique uses nature’s own in-built means to ensure its balance.

It is believed that Biological control or bio-control has been used successfully against invasive species for over 100 years. A biocontrol agent is therefore only proposed for field release in the invaded range after intensive research and vigorous safety testing to ensure it is specific to the plant or pest which needs to be controlled. Care should be taken that the bio-control agents do not attack or harm other beneficial or native plants and insects.

Why bio-control is needed?

The ever increasing spread of invasive species or spread of non-native/exotic species becoming threat to native biodiversity due various reasons which may be natural or man-made has resulted into demand for environmental friendly way of controlling or preventing the exotic species to spread in non-native range. Biological control is one such way of controlling the spread of invasive species. Increasing trade and travel between nations has increased the number of plants and other non-native species arriving in new countries.

Biological control has advantage over other methods such as use of pesticides or chemical which are harmful to the environment and have negative impact on the biodiversity including humans. It’s also economically efficient and sustainable, as once self-replicating and co-evolved natural enemies are established which provide control indefinitely without further cost or intervention.

Characteristics of Biological Control Agents

Biological control agents are highly specific and usually found in the native range of the invasive species. Candidate Biological Control agents undergo wide-ranging security tests to evaluate undesirable hazards to the environment, native, wild, agricultural species or to say biodiversity including humans. Bio-control is the most cost effective and environmental friendly way out to manage IAS because as soon as it becomes effective it does not require re-application like chemicals or harmful pesticides, weedicides, fungicides etc. Most biocontrol agents for weeds and insects, once established, are self-sustaining and don't have to be reapplied.

Types of biological control

There are three basic biological pest control strategies: Importation (classical biological control), augmentation and conservation (Radcliffe *et al.*, 2009).

- Importation or Classical: Initially small numbers of natural enemies are released in target pest areas for long-term control.
- Augmentation: Large numbers of natural enemies are released to control a target pest for a short amount of time.
- Conservation: Changing environmental conditions to aid in natural enemy survival (Radcliffe *et al.*, 2009).

Advantages of Biological Control:

Biological control is environmental friendly and prevents the use of man-made chemicals that affect an ecosystem. It also minimized the use of weedicides/herbicides required for control of weeds. They are cost effective as only initial costs for multiplication of control agent is required then they perpetuate on their own and later monitoring costs. The bio-control agents are host specific whether insects or pathogens and target the specific host by locating them. They also do not pose any threat to the environment, agricultural crops, beneficial organisms and human health.

Limitations of Biological Control

Bio control agents are affected by climate which slows down their activity and hence all problems related to invasive species cannot be solved. An effective quarantine system of bio-security import regulations such as a candidate biocontrol agent must be assessed using internationally recognized protocols before introducing to any place. Thus an integrated approach is essential for management of invasive species which involves prevention, regular monitoring, cultural control, Quarantine check and use of chemicals as a last resort. Cultural control though labour intensive is most effective as it is also a source of livelihood. Biological control cannot be applied to control all species as some invasive species do not have any effective control agents and in such cases research efforts have to be made to develop new effective strains (Myers, 2000).

The challenge: Bio-Control Monitoring

Monitoring biological control agents is an essential component of a successful biological control program for accurately documenting the impact of weed management practice. It should cover vegetation cover, target weed density, biological control abundance and changes over the time.

Research should emphasize the following aspects:

- Invasive species biology, ecology, interactions and impacts
- Forecasting and prioritizing Invasive species

- Identifying and detecting Invasive species
- Managing Invasive species and altered systems
- Monitoring is the most essential tool for managing invasive species.

BIOLOGICAL CONTROL OF IMPORTANT INVASIVE SPECIES

Julien and Griffiths (1998) have brought out a world catalogue of agents and their targeted weeds. *Salvinia molesta* Mitchell (Family: Salviniaceae) and *Eichhornia crassipes* (Martius) (Family: Pontederiaceae) are problematical for farmers in many places. Studies by Joy *et al.* (1985) and Singh, (2001) proved the efficiency of managing *Salvinia* and *Eichornia* with biocontrol agents. The curculionid weevil, *Neochetina eichhorniae* Warner and *N. bruchi*, natives of South America were introduced to India in 1982 as control agents against *Eichornia* and established in many places. Biological control of aquatic weed water hyacinth was achieved by releases of *Neochetina eichhorniae* which holds promise for control of water hyacinth in India (Manian and Shanmughavel 2003). The insect eats away the leaves resulting into drying of shoot of water hyacinth.

Mimosa pudica, an introduced weed, has become a serious problem in coconut and cashew plantations. Similarly it has been reported in glades of natural forests and also in teak plantations. Manual removal of this weed is difficult, due to its spiny nature. *Chromolaena odorata* is a perennial shrub, native to South and Central America, and capable of establishing in a wide variety of agro-ecological conditions. Chromolaena odorata is a serious problem in pastures, forests, orchards and commercial plantations in South and Northeast India (Singh, 1998). It is widespread in coconut, rubber, oil palm, tea, teak, coffee and cardamom plantations and also in natural forests. Several insects and pathogens have been reported to be useful as biocontrol agents, but none has been effective in a practical way. Further, this weed is also being used as a source of green manure by farmers in many parts of the country.

In the agricultural sector more attention to the management of alien invasive weeds is given because of the social needs attached to the farming community. No serious attempt has been made in the past to look at the spread of Invasive species in different habitats. Works on biological control of invasive species in India are mainly by Kumar (1993, 2005, 2006, 2009, 2011, 2012, 2013); Kumar and Bhan (1996); Kumar and Ray (2010, 2011); Kumar and Saraswat (2001); Kumar and Varshney (2007, 2010) and Rao and Chauhan (2015).

Invasive Alien Species (IAS) have become an environmental concern in India. The most important invasive species in India are *Lantana camara, Acacia mearnsii, Parthenium, Mikania micrantha* and *Prosopis juliflora*. Biological Control of following species discussed in detail:

- *Lantana camara*
- *Acacia mearnsii*
- *Parthenium hysterophorus*
- *Mikania micrantha*
- *Prosopis juliflora*

Biological Control of *Lantana camara*

In forests, *Lantana* is considered as a potential fire hazard in deciduous forests and it is combustible even when green. Thus this weed can be dangerous in national parks and sanctuaries. *Lantana* also competes with agricultural crops and has an allelopathic effect-inhibiting the growth of other plants. This weed is reported to be of huge concern in Teak, Eucalypt and Coffee plantations in India. Various mechanical, cultural, chemical and biological methods have been tried to minimize the spread of *Lantana* in forests and pastoral lands. Serious attempts were made by the Forest Research Institute, Dehra Dun to identify insects that feed on *Lantana* (Beeson and Chatterjee, 1939). In 1941, a tingid bug, *Teleonema scrupulosa,* was imported from Australia as a biocontrol agent. However, this insect fed on *Tectona grandis* (teak) and hence the insect culture was destroyed (Khan, 1944). A number of bio-control agents including insects have been used to control spread of *L. camara,* details are mentioned in Table 1.

Table 1. *Biological Control Agents for Lantana camara*

Species Name of Agent	Country Established/ Found, Year	Reference
Aceria lantanae (Cook) Order: Acari Family: Eriophyidae	Australia, 2012, Republic of South Africa, 2007	Anon. (2012), Besaans (2012), King (2000), Mabuda (2005), Smith *et al.* (2010), Urban (2013), Urban *et al.* (2011)
Aconophora compressa Walker Order: Hemiptera Family: Membracidae	Australia, 1995	Day (2012a), Day (2013), Day *et al.* (2003), Day *et al.* (2003), Manners *et al.* (2011), Palmer *et al.* (1996)
Aerenicopsis championi Bates Order: Coleoptera Family: Cerambycidae	Australia, 1995, Hawaii USA, 1902	Day (2012a), Day *et al.* (2003), Conant *et al.* (2013), Gardner and Davis (1982), Perkins and Swezey (1924), Waterhouse and Norris (1987), Weber (1956)
Alagoasa parana Samuelson Order: Coleoptera Family: Chrysomelidae	Australia, 1981, Republic of South Africa, 1985	Cilliers and Neser (1991), Day (2012a), Day *et al.* (2003), King (2000), Winder *et al* (1988),
Autoplusia illustrata Guenée Order: Lepidoptera Family: Noctuidae	Australia, 1976, Republic of South Africa, 1978	Cilliers (2013), Cilliers and Neser (1991), Day (2012a, 2013), Day *et al.* (2003), King (2000)Willson (1979)
Calycomyza lantanae (Frick) Order: Diptera Family: Agromyzidae	Australia, 1974, Fiji, 1996, Republic of South Africa, 1982	Anon. (1973), Baars and Heystek (2003), Baars and Neser (1999), Cilliers and Neser (1991), Day (2012a, 2013), Day (2013), Day and Zalucki (2009), Day *et al.* (2003), Lal (1997), Neser (1998), Taylor (1989), Urban *et al.* (2011)
Charidotis pygmaea Klug Order: Coleoptera Family: Chrysomelidae	Australia, 1994	Day (2012a, 2013), Day and McAndrew (2002), Day et al. (2003)
Coelocephalapion camarae Kissinger Order: Coleoptera Family: Brentidae	Republic of South Africa, 2007	Conant *et al.* (2013), Heystek (2007, 2013), Heystek and Kistensamy (2009), Urban *et al.* (2011)
Cremastobombycia lantanella Busck Order: Lepidoptera Family: Gracillariidae	Hawaii USA, 1902	Conant *et al.* (2013), Gardner and Davis (1982), Goeden (1978), Anon. (2013), Swezey (1923), Waterhouse and Norris (1987)

Crocidosema lantana Busck Order: Lepidoptera Family: Tortricidae	Fiji, 1995 Hawaii USA, 1902; Marshall Islands,1948; Republic of South Africa, 1984	Anon. (2013), Baars (2003), Baars and Heystek (2003) Baars and Neser (1999), Day and Zalucki (2009), Day and Zalucki (2009),Day et al. (2003), Gardner and Davis (1982), Goeden (1978), Goeden (1978), King (2000) Neser (1998), Rao et al. (1971); Davis et al. (1992), Swezey (1923), Waterhouse and Norris (1987), Zimmerman (1978); Gutierrez and Forno (1989),
Diastema tigris Guenée Order: Lepidoptera Family: Noctuidae	Australia, 1965; Federated States of Micronesia, 1955, Fiji, 1954, Hawaii USA, 1954, India, 1971; Mauritius, 1967; St Helena, 1971; Tanzania, 1967; Uganda, 1963; Zambia, 1970	Anon. (1967), Anon. (1971), Anon. (2013), Bhumannavar (2013),Conant et al. (2013), Day (2012a, 2013), Day and Zalucki (2009), Day et al. (2003),Denton et al. (1991b), Fowler et al. (2000), Gardner and Davis (1982), Goeden (1978), Greathead (1971), Krauss (1962), Löyttyniemi (1982), Muniappan and Viraktamath (1986), O'Connor (1950), Rabindra and Bhumannavar (2009), Rao (1971), Rao et al. (1971), Sankaran (1973), Schreiner (1989), Waterhouse and Norris (1987), Weber (1955), Wilson (1960); Day and Zalucki (2009)
Ectaga garcia Becker Order: Lepidoptera Family: Oecophoridae	Australia, 1993	Day (2012a, 2012b, 2013), Day et al. (1998, 2003)
Eutreta xanthochaeta Aldrich Order: Diptera Family: Tephritidae	Australia, 1914; Hawaii USA, 1902; Republic of South Africa, 1983	Cilliers and Neser (1991), Davis et al. (1992), Day (2012a), Day and Zalucki (2009), Gardner and Davis (1982), Goeden (1978), Harley (1974), King (2000), Mabuda (2005), Swezey (1923), Taylor (1989), Waterhouse and Norris (1987), Wilson (1960)
Falconia intermedia (Distant) Order: Hemiptera Family: Miridae	Australia, 2000; Republic of South Africa, 1999	Baars et al. (2003), Day (2012a, 2013), Day et al. (2003); Heystek and Olckers (2004), King (2000), Urban et al. (2011)
Hepialus sp. Order: Lepidoptera Family: Hepialidae	Hawaii USA, 1902	Conant et al. (2013), Gardner and Davis (1982), Perkins and Swezey (1924), Waterhouse and Norris (1987)
Hypena laceratalis Walker Order: Lepidoptera Family: Erebidae	Australia, 1965; Federated States of Micronesia, 1958; Fiji, 1960; Guam, 1967; Hawaii USA, 1957; Mauritius, 1960	Anon. (2013), Broughton (2000), Davis (1959, 1960), Davis et al. (1992),Day (2012a), Day et al. (2003), Denton et al. (1991a, 1991b), Gardner and Davis (1982), Goeden (1978), Greathead (1971), Harley (1974), Harley (1997), Krauss (1962), Muniappan (1988), Muniappan (2013), Nafus and Schreiner (1989), Rao (1971) Rao et al. (1971), Schreiner (1989), Simmonds (1967), Szent-Ivany (1964), Taylor (1989), Waterhouse and Norris (1987),

Lantanophaga pusillidactyla (Walker) Order: Lepidoptera Family: Pterophoridae	Federated States of Micronesia, 1948; Hawaii USA, 1902; Hong Kong, 1933; Palau, 1960; Republic of South Africa, 1984	Cilliers and Neser (1991), Davis et al. (1992), Day and Zalucki (2009),Day et al. (2003), Denton et al. (1991a, 1991b), Gardner and Davis (1982), Goeden (1978), Goeden (1978), Muniappan (2013), Neser (1998), Rao et al. (1971), Schreiner (1989), Swezey (1923), Waterhouse and Norris (1987)
Leptobyrsa decora Drake Order: Hemiptera Family: Tingidae	Australia, 1969; Cook Islands, 1972; Fiji, 1971; Ghana, 1971; Guam, 1971; Hawaii USA, 1970; Palau, 1977; Republic of South Africa, 1972; Tonga, 1969; Zambia, 1970	Anon. (1970), Anon. (1971), Anon. (2013), Broughton (2000), Cilliers and Neser (1991), Conant et al. (2013), Davis (1971), Davis et al. (1992),Day (2012a, 2013), Day and Zalucki (2009), Day et al. (2003), Denton et al. (1991b), Gardner and Davis (1982), Harley (1974), Harley and Kassulke (1971),Kamath (1979), King (2000), Löyttyniemi (1982), Muniappan (1988), Nafus and Schreiner (1989), Scheibelreiter (1980), Taylor (1989), Waterhouse and Norris (1987)
Longitarsus bethae Savini & Escalona Order: Coleoptera Family: Chrysomelidae	Republic of South Africa, 2007	King (2000), Simelane (2005, 2007, 2010), Urban et al. (2011)
Neogalea sunia (Guenée) Order: Lepidoptera Family: Noctuidae	Australia, 1957; Federated States of Micronesia, 1955; Hawaii USA, 1955	Anon. (2013), Davis (1971), Davis and Krauss (1962b), Davis et al. (1992),Day (2012a, 2013), Day and Zalucki (2009), Day et al. (2003), Denton et al. (1991b), Gardner and Davis (1982), Goeden (1978), Goeden (1978), Harley (1974), Haseler (1966), Krauss (1962), Schreiner (1989), Taylor (1989) Waterhouse and Norris (1987), Weber (1956), Wilson (1960)
Octotoma championi Baly Order: Coleoptera Family: Chrysomelidae	Australia, 1975; Fiji, 1976; Hawaii USA, 1954; Republic of South Africa, 1978	Cilliers (1983), Cilliers and Neser (1991), Conant et al. (2013), Day (2012a, 2013), Day et al. (2003), Day and Zalucki (2009), Gardner and Davis (1982), King (2000), Krauss (1962), Lal (1997), Oishi (2011), Weber (1955), Willson (1979)
Octotoma gundlachi Suffrain Order: Coleoptera Family: Chrysomelidae	Hawaii USA, 1953	Hayes (2013)
Octotoma scabripennis Guérin-Méneville Order: Coleoptera Family: Chrysomelidae	Australia, 1966; Cook Islands, 1973; Fiji, 1971; Ghana, 1971; Hawaii USA, 1902; India, 1972; New Caledonia,	Anon. (1971, 1972, 1973), Baars and Heystek (2003), Cilliers (1983, 1987a), Cilliers and Neser (1991), Cochereau and Mille (2008), Day (2012a, 2013), Day and Zalucki (2009), Day and Zalucki (2009), Day et al. (2003), Goeden (1978), Gutierrez and Forno (1989),

	1977; Niue, 1981; Republicof South Africa, 1971; Solomon Islands, 1993	Harley (1973, 1974, 1997), Kamath (1979), King (2000), Muniappan and Viraktamath (1986), Orapa (2013), Perkins and Swezey (1924), Rabindra and Bhumannavar (2009), Scheibelreiter (1980), Taylor (1989), Urban et al. (2011), van Harten (1995), Waterhouse and Norris (1987), Weber (1956).
Ophiomyia camarae Spencer Order: Diptera Family: Agromyzidae	Australia, 2007; Republic of South Africa, 2001; Uganda, 2008	Day (2012a, 2013), Day et al. (2009), Simelane (2002), Heystek (2006), Simelane (2002), Simelane and Phenye (2004, 2005), Urban et al. (2011)
Ophiomyia lantanae (Froggatt) Order: Diptera Family: Agromyzidae	Australia, 1914; Cook Islands, 1972; Federated States of Micronesia, 1948; Fiji, 1911; French Polynesia, 1916; Guam, 1971; Hawaii USA, 1902; Hong Kong, 1933; India, 1921; Kenya, 1958; New Caledonia, 1911; Republic of South Africa, 1961	Anon. (1916), Baars and Heystek (2003), Baars and Neser (1999), Broughton (1999), Cilliers (1977, 1987b), Cilliers and Neser (1991), Conant et al. (2013), Day et al. (2003), Davis et al. (1992),Day (2012a), Day (2013), Day and Zalucki (2009), Denton et al. (1991a, 1991b), Gardner and Davis (1982), Goeden (1978), Greathead (1968, 1971), Gutierrez and Forno (1989), Hammes and Putoa (1986), Harley (1974), Joseph (1972), Kermack (1928), Meyer (2013a), Muniappan and Reddy (2003), Nafus and Schreiner (1989), Nishida (2008b),O'Connor (1950), Oosthuizen (1964), Perkins and Swezey (1924), Rabindra and Bhumannavar (2009), Rao (1971), Rao et al. (1971), Sankaran (1973), Sasakawa (1963b), Schreiner (1989), Simmonds (1932), Simmonds (1934), Spencer (1962), Spencer (1973), Subramanian (1934), Tryon (1912), Vivian-Smith et al. (2006), Waterhouse and Norris (1987),Waterhouse and Norris (1987),Wilson (1960).
Orthezia insignis Browne Order: Hemiptera Family: Ortheziidae	Hawaii USA, 1902; India, 1921	Day et al. (2003), Kumar (1993), Muniappan and Viraktamath (1986), Perkins and Swezey (1924), Rao (1920), Waterhouse and Norris (1987)
Parevander xanthomelas (Guérin-Méneville) Order: Coleoptera Family: Cerambycidae	Hawaii USA, 1902	Conant et al. (2013), Gardner and Davis (1982), Perkins and Swezey (1924), Waterhouse and Norris (1987)
Passalora lantanae (Chupp) U. Braun & Crous var. lantanae Order: Dothideomycetes Family: Capnodiales	Republic of South Africa, 2002	Den Breeÿen, (2004), Den Breeÿen and Morris (2003), King (2000), Urban et al. (2011)

Plagiohammus spinipennis (Thomson) Order: Coleoptera Family: Cerambycidae	Australia, 1967; Guam, 1973; Hawaii USA, 1960; Palau, 1977; Republic of South Africa, 1973	Anon. (2013), Cilliers (1977, 1983), Cilliers and Neser (1991), Conant et al. (2013), Davis (196, 1970), Davis and Krauss (1962b, 1963), Davis and Krauss (1964, 1966, 1967), Davis et al. (1992), Day (2012a, 2013), Day and Zalucki (2009), Day et al. (2003), Denton et al. (1991a, 1991b), Gardner and Davis (1982), Harley and Kunimoto (1969), King (2000), Muniappan (1988), Nafus and Schreiner (1989), Schreiner (1989), Waterhouse and Norris (1987)
Prospodium tuberculatum (Spegazzini) Arthur Order: Pucciniomycetes Family: Pucciniales	Australia, 2001	Day (2012a, 2013), Day et al. (2003), Tomley and Riding (2002)
Pseudopyrausta santatalis (Barnes & McDunnough) Order: Lepidoptera Family: Crambidae	Federated States of Micronesia, 1955; Fiji, 1954; Hawaii USA, 1953	Anon. (2013),Conant et al. (2013), Day et al. (2003), Day and Zalucki (2009), Denton et al. (1991b), Schreiner (1989), Rao (1971), Rao et al. (1971), Davis and Krauss (1962a), Gardner and Davis (1982), Waterhouse and Norris (1987), Weber (1954, 1955)
Salbia haemorrhoidalis Guenée Order: Lepidoptera Family: Crambidae	Australia, 1958; Federated States of Micronesia, 1958; Fiji, 1958; Guam, 1958; Hawaii USA, 1956; India, 1971; Mauritius, 1965; Palau, 1960; Republic of South Africa, 1962; Tanzania, 1967; Uganda, 1964; Zambia, 1970	Anon. (1968), Anon. (1970), Baars (2003), Baars and Neser (1999), Cilliers (2013), Cilliers and Neser (1991), Davis (1959), Davis and Krauss (1962a), Davis et al. (1992),Day (2012a, 2013),Day et al. (2003), Denton et al. (1991a, 1991b), Fowler et al. (2000), Gardner and Davis (1982), Goeden (1978),Greathead 1968, 1971), Harley (1974), Haseler (1966), (Heystek (2006), King (2000), Klein (2013), Krauss (1962), Löyttyniemi (1982), Muniappan (1988), Muniappan (2013), Muniappan and Viraktamath (1986), Nafus and Schreiner (1989), Neser (2013), O’Connor (1950), Oosthuizen (1964), Rabindra and Bhumannavar (2009),Rao (1971), Rao et al. (1971),Sankaran (1973), Schreiner (1989), Schreiner (1989), Taylor (1989), Urban et al. (2011), Waterhouse and Norris (1987), Weber (1957), Wilson (1960)
Septoria sp. Order: Dothideomycetes Family: Capnodiales	Hawaii USA, 1997	Conant (2013), Conant et al. (2013), Ko (2012), Trujillo (1997, 2005 a & b)
Strymon bazochii (Godart) Order: Lepidoptera Family: Lycaenidae	Australia, 1914; Fiji, 1923; Hawaii USA, 1902	Davis et al. (1992), Day (2012a, 2013), Gardner and Davis (1982), Goeden (1978), Harley (1974), Kermack (1928), Matsunaga (2013), O’Connor (1950), Perkins and Swezey (1924), Rao (1971), Rao et al. (1971), Simmonds (1932), Swezey (1923), Waterhouse and Norris

		(1987), Wilson (1960); Day et al. (2003), Zimmerman (1958 a).
Teleonemia elata Drake Order: Hemiptera Family: Tingidae	Australia, 1969; Cook Islands, 1973; Republic of South Africa, 1972; Uganda, 1972; Zambia, 1970	Anon. (1970),Anon. (1972),Day (2012a, 2013), Cilliers (1977, 1983), Day and Zalucki (2009), Day et al. (2003), Cilliers and Neser (1991), Waterhouse and Norris (1987), Löyttyniemi (1982), Harley (1974)
Teleonemia harleyi Froeschner Order: Hemiptera Family: Tingidae	Australia, 1969	Day (2012a), Day et al. (2003), Harley (1974), Taylor (1989)
Teleonemia prolixa (Stål) Order: Hemiptera Family: Tingidae	Australia, 1974	Day (2012a, 2013), Day et al. (2003), Harley and Kassulke (1971)
T*eleonemia scrupulosa* Stål Order: Hemiptera Family: Tingidae	Ascension Island, 1973; Australia, 1936; Federated States of Micronesia, 1948; Fiji, 1928; French Polynesia, 1986; Ghana, 1971; Hawaii USA, 1902; Madagascar, 1961; New Caledonia, 1936; Niue, 1981; Northern Mariana Islands, 1963; Palau, 1960; Papua New Guinea, 1973; Republic of South Africa, 1961; Republic of South Africa, 1971; Samoa, 1936; Solomon Islands, 1993; St Helena, 1971; Tanzania, 1958; Tonga, 1937; Uganda, 1960; Uganda, 1962; Vanuatu, 1935; Zambia, 1962; Zimbabwe, 1961	Anon. (1971, 1972), Baars and Heystek (2003), Baars and Neser (1999), Breniere (1965), Cilliers (1977, 1987a, 2013), Cilliers and Neser (1991), Davies and Greathead (1967), Davis et al. (1992), Day (2012a, 2013), Day and Zalucki (2009), Day et al. (2003), Denton et al. (1991a, 1991b), Distant (1907), Fowler (1997, 2011), Fyfe (1935), Gardner and Davis (1982), Gatimel (2013), Goeden (1978), Greathead (1968, 1971), Gutierrez and Forno (1989), Hammes and Putoa (1986), Harley (1973), Harley and Kassulke (1971), Heystek (2006), King (2000), Krauss (1962), Lever (1938), Nafus and Schreiner (1989), Neser and Annecke (1973), Nishida (2008a), O'Connor (1950), Oosthuizen (1964), Pemberton (2000), Rao (1971) Rao et al. (1971), Scheibelreiter (1980), Schreiner (1989), Simmonds (1928, 1931, 1932), Taylor (1989), Urban et al. (2010 a), Urban et al. (2011), Waterhouse and Norris (1987), Wilson (1960), Wilson and Forno (1995), Young (1982)
Tmolus echion (L.) Order: Lepidoptera Family: Lycaenidae	Fiji, 1922; Hawaii USA, 1902	Davis et al. (1992), Day and Zalucki (2009), Day et al. (2003), Gardner and Davis (1982), Goeden (1978), Kermack (1928), O'Connor

		(1950), Perkins and Swezey (1924), Rao (1971), Rao et al. (1971), Simmonds (1932, 1934), Swezey (1923), Waterhouse and Norris (1987), Zimmerman (1958 a),
Uroplata fulvopustulata Baly Order: Coleoptera Family: Chrysomelidae	Australia, 1976; Fiji, 1976; Republic of South Africa, 1978	Day (2012a, 2013), Day et al. (2003), Harley (1973), Taylor (1989), Day and Zalucki (2009), Lal (1997), Cilliers (1983), Cilliers and Neser (1991), King (2000)
Uroplata girardi Pic Order: Coleoptera Family: Chrysomelidae	Ascension Island, 1973; Australia, 1966; Cook Islands, 1969; Federated States of Micronesia, 1963; Fiji, 1969; Ghana, 1971; Hawaii USA, 1974; India by FRI, 1972; Mauritius, 1967; New Caledonia, 1977; Niue, 1993; Northern Mariana Islands, 1963; Palau,1974; Papua New Guinea, 1972; Philippines, 1985; Republic of South Africa, 1974; Samoa, 1975; Solomon Islands, 1992; Zambia, 2009	Anon. (1967, 1971, 1973, 1974), Anon. (1970, 1972), Anon. (1975, 1977-78), Anon. (2013), Baars (2003), Baars and Heystek (2003), Baars and Neser (1999), Bule (2013), Cilliers (1983, 1987a), Cilliers and Neser (1991), Cochereau and Mille (2008), Cock (1986), Cock (1986), Cock and Godfray (1985), Davis and Krauss (1962b), Davis and Krauss (1964), Davis et al. (1992), Day (2012a), Day (2013), Day (2013), Day and Zalucki (2009), Day and Zalucki (2009), Day et al. (2003), Day et al. (2003), Day et al. (2003), Day et al. (2003), Day et al. (2003), Denton et al. (1991a), Denton et al. (1991b), Fowler (1997), Fowler (2011), Fowler et al. (2000), Gardner and Davis (1982), Goeden (1978), Greathead (1971), Gutierrez and Forno (1989), Harley (1973, 1974, 1997), Heystek (2006), Heystek (2006), Kairo (1998), Kairo (1998), Kairo (1998), Kamath (1979), Klein (2013), Lal (1997), Löyttyniemi (1982), Matsunaga (2013), McConnachie (2013), Muniappan (2013), Muniappan and Viraktamath (1986), Nafus and Schreiner (1989), Orapa (2005), Rabindra and Bhumannavar (2009), Rao et al. (1971), Rao et al. (1971), Scheibelreiter (1980), Schreiner (1989), Taylor (1989), Urban et al. (2011), Urban et al. (2011), van Harten (1995), Waterhouse and Norris (1987), Waterhouse and Norris (1987), Waterhouse and Norris (1987), Winder et al. (1988), Witt (2013)
Uroplata lantanae Buzzi & Winder Order: Coleoptera Family: Chrysomelidae	Australia, 1977, Republic of South Africa, 1984	Day (2012a), Day (2013), Day et al. (2003), Taylor (1989), Winder et al. (1984), Cilliers and Neser (1991), King (2000)
Phenacoccus parvus Morrison Order: Hemiptera Family: Pseudococcidae	Australia, 1988	Williams and Hamon (1994), Day (2012a, 2013), Day et al. (2003), Swarbrick and Donaldson (1991)

The noxious weed *L. camara* has been controlled by mechanical means such as slashing, uprooting and burning, by use of herbicides but this result into exorbitant cost of control. Since mechanical and chemical control options were expensive and ineffective, a bio-control programme was initiated in South Africa in 1961 and about 22 insect species and a fungus was experimented as biological control agents. Out of these 10 species of insects and the one fungus species gave considerable results.

Use of biological control agents such as natural parasites of *L. camara* also helps in its control. Sapsuckers insects such as *Teleonemia scrupulosa* stal (tinged), *Orthezia insignis* (Coccid) have been evaluated for its control. The success of control limited due to cultivars of Lantana which played a significant role in the field conditions. Only one introduced species, Teleonemia scrupulosa and the two indigenous species, *Hypena laceratalis* and *Aristea onychote* were able to sustain populations on non-target species in the field in the absence of *L. camara* (Heystek, 2006). The tinged insect was not reported to feed on other species of the family Verbenaceae such as teak. The other insect *Orthezia insignis* commonly known as Kew bug or *Lantana* bug were restricted to the ventral side of the leaves mostly abundant along the mid rib feeding on the plant sap. Both the tingids and coccids, due to their intense sap sucking in the tender shoots, suppressed the vigor of *Lantana* bushes and impeded their reproductive potential.

It is also reported that in spite of 36 control agents tested across 33 regions have not resulted into a successful result. The reason of failure was attributed to hybridization of *L. camara* and its genetic diversity. In India some attempts to control *L. camara* by use of tipid bugs gave positive results to some extent (Cilliers and Neser, 1991). An insect feeding on *Lantana* was explored as early as 1902 by Koebele. He shipped 23 insect species to Hawaii (Goeden, 1978). Natural enemies of invasive species *Lantana* such as lantana seed fly, *Ophiomyia lantanae* (Froggatt) (Diptera: Agromyzidae), was transferred from Hawaii to New Caledonia in 1908-1909 and to Fiji in 1911 (Rao *et al.*, 1971). These shipments marked the beginnings of a tradition of transfer projects (DeBach, 1964), involving biological control agents of proven worth to other countries with the same noxious plants. Three more species of *Lantana* insects were then transferred from Hawaii to Fiji during 1922-1928 (Rao et al., 1971).

Limitations of Biological Control of *Lantana*

The control of *L. camara* by biological agents faces problems due to cultivar or several forms of *L. camara.* The insects used as biological agents show preference for some cultivars of *Lantana cama*ra only (Cilliers and Neser, 1991). A better understanding of the functional relationships and interactions between the various cultivars of *L. camara* and insect herbivores may improve the chances of succeeding with biological control (Cilliers and Neser, 1991). Similarly, the flower-galling mite *Aceria lantanae* (Cook) (Trombidiformes: Eriophyidae) was released for the biological control of *L. camara* L. (Verbenaceae) in South Africa in 2007 and faced the problems due to cultivars.

Introduction of other exotic natural enemies that have proven beneficial elsewhere, namely *Calcomyza lantanae, Neogalea esula, Plagiohammus spinipennls and Salbia haemorrhoidalis* is recommended to suppress the weed (Muniappan and Viraktamath, 2008). Distribution of Lantana in east Africa and its impact on livelihood was studied by Shackleton *et al.* (2017). It is recommended that an integrated control method where herbicidal and physical measures with the biological control could be adopted in restricting the spread of *Lantana* (Manian and Shanmughavel, 2003). Knowledge of the likely potential distribution of this invasive species under current and future climate will be useful in planning better strategies to manage the invasion. A process-oriented niche model of *L. camara* was developed using CLIMEX to estimate its potential distribution under current and future climate scenarios. The model was calibrated using data from several knowledge domains, including phenological observations and geographic distribution records. The potential distribution of lantana under historical climate exceeded the current distribution in some areas of the world, notably Africa and Asia. However, some areas were identified in North Africa, Europe and Australia that may become climatically suitable under future climates. In South Africa and China, its potential distribution could expand further inland. These results can inform strategic planning by biosecurity agencies, identifying areas to target for eradication or containment. Distribution maps for potential risk of invasion can be useful tools for public awareness campaigns, especially in countries that have been identified as becoming climatically suitable for *L. camara* under the future climate scenarios (Baars and Neser, 1999; Taylor et al., 2012).

Biological Control of Acacia mearnsii

A. mearnsii is a highly invasive species, and listed as one of the World's 100 Worst Invaders (ISSG, 2007). It is also known to be invasive in California, USA, Burundi, Ethiopia, Kenya, Malawi, Rwanda, Tanzania, Uganda, Zimbabwe, Jamaica, Brazil, New Zealand and Réunion (Seburanga, 2015). *A. mearnsii* is recorded as being highly competitive and eventually reducing the presence of native and/or indigenous vegetation, especially in South Africa (De Wit, 2001; ISSG, 2007).

Seed feeders and a mycoherbicide have been used to control *A. mearnsii* (Henderson, 2001). Two agents for the purpose of biological control in South Africa are the seed weevil *Melenterius maculatus* and a native South African fungus *Cylindrobasidium laeve* that attacks stumps and is applied after felling to prevent resprouting. Cecidomyiid midge, *Dasineura rubiformis*, which forms galls in the flowers and prevents pod development was released to control black wattle and its impact were studied by Impson *et al.*, (2008, 2013).

Table 2. *Biological Control Agents for Acacia mearnsii*

Species Name of Agent	Country Established/ Found/ Year	Reference
Melanterius maculatus Lea Order: Coleoptera Family: Curculionidae	Republic of South Africa, 1993	Impson *et al.* (2008, 2011, 2013), Dennill *et al.* (1999), Impson *et al.* (2008, 2009), King, (2000)
Dasineura rubiformis Kolesik Order: Diptera Family: Cecidomyiidae	New Zealand, 2011 Republic of South Africa, 2001	Hayes (2013), Anon. (2011) Impson *et al.* (2008, 2009, 2011), King (2000)
BIOHERBICIDE *Cylindrobasidium laeve* (Pers.) Chamuris Order: Agaricomycetes Family: Agaricales	Republic of South Africa, 1997	Impson *et al.* (2011), King (2000), Lennox *et al.* (2000), Morris *et al.* (1999), Wood (2013)

Biological Control of Parthenium hysterophorus

Parthenium hysterophorus L., an obnoxious Asteraceous weed, has spread over millions of hectares of land in India after its inadvertent introduction in the 1950s. This weed has reduced the yield of grasses and crops. It is a health hazard to sensitized humans and cattle and the routine weed control methods have failed to check its spread.

Biological control is the most economical and practical way to keep the weed carrot grass under control as it is a weed of waste and fallow land. In past, attempts were made to review work on biological control of Parthenium in context to India, Australia and global situations (Singh 1989, 1997; Sushilkumar, 1993; Sushilkumar and Bhan, 1995a, McFadyan 1992; Dhileepan and McFadyen, 1997; Evans 1997, Dehileepan, 2009).

So far, some eleven species have been tested as biological control agents for the control of carrot grass *Parthenium hysterophorus* (Asteraceae). Nine have established and the two most effective are *Zygogramma bicolorata*

(Coleoptera: Chrysomelidae) and a stem galling moth *Epiblema strenuana* (Lepidoptera: Tortricidae) (Dhileepan, 2001). Other species are Leaf-mining moth Bucculatrix parythenica, a stem-galling weevil *Conotrachelus albocinereus* and a root-boring moth Carmenta ithacae.

Based on well documented success by Mexican beetle, *Zygogramma bicolorata* (Coleoptera: Chrysomelidae) in other countries where they were introduced, beetles were imported in 1982 from Mexico to Bangalore. The species have now established in Haryana, Punjab, Uttar Pradesh, Uttaranchal, Madhya Pradesh, Tamilnadu, Karnataka, Andhra Pradesh, Himachal Pradesh and Maharashtra (Jayanth, 1987). It defoliates and kills the weed and reduces seed production by damaging the young flowering tops (Dhileepan, 2003).

In Australia and Africa a stem boring beetle *Listronotus setosipennis* and a seed weevil *Smicronyx lutulentus* has been used for its control (Hasler, 1976). Rust fungi *Puccinia abrupta* var. *partheniicola* (winter rust) and *Puccinia xanthii* (summer rust) have been also used for its control in South Africa (Fauzi *et al.*, 1999). *Cassia uniflora* a leguminous shrub is found effective to suppress the growth of parthenium. It has successfully replaced *Parthenium* by over 90% in an area of 4800 m^2 over a period of 5 years. The leachate from germinating seeds of *C. uniflora* inhibits the germination of Parthenium seeds and hampered the establishment of summer generation of *Parthenium* due to allelopathy. The robust colonies of C. uniflora prevented the establishment of winter generation of *Parthenium* below them. *C. uniflora* is dispersed slowly to neighbouring places through rainwater. Sustained efforts to introduce *C. uniflora* hold out great promise of Parthenium control with financial benefits (Joshi, 1991).

Kumar (2009) extensive worked on biology, population dynamics, damage potential, economic benefit, diapause and activity enhancement of *Zygogramma bicolorata*. A combined approach for the management of Parthenium weed using biological control agents (*Epiblema strenuana* Walker, *Zygogramma bicolorata Pallister, Listronotus setosipennis* Hustache and *Puccinia abrupta* var. *partheniicola*) and plant suppression species in Australia and elsewhere was undertaken by Shabbira *et al.*, (2013).

Biological control through competitive plants can be achieved either by conservation of naturally occurring plant species or through deliberate use of known competitive plant species to suppress the growth of the *Parthenium.* Most of the work on this approach has been carried out in India and now gaining momentum in other countries too. Biological control through competitive plants in India was reported first time by Maheswari (1966) from a wasteland weed *Xanthium strumarium* to compete with *Parthenium.* Singh (1983) reported that *Cassia sericea (C. uniflora)* compete and suppress *Parthenium* and may be used for its biological management. Biological control agent of Parthenium is given in Table 3.

Table 3.
Biological Control Agents for Invasive Plant Species Parthenium hysterophorus

Species Name of Agent	Country Established/ Found/ Year	Reference
Bucculatrix parthenica Bradley Order: Lepidoptera Family: Bucculatricidae	Australia, 1984	Dhileepan and McFadyen (2012), McClay *et al.* (1990), McFadyen (1985, 1992)
Carmenta sp. *nr ithacae* (Beutenmüller) Order: Lepidoptera Family: Sesiidae	Australia, 1998	Dhileepan (2012), Dhileepan and McFadyen (2012), Palmer *et al.* (2010)

Conotrachelus albocinereus Fiedler Order: Coleoptera Family: Curculionidae	Australia, 1995	Dhileepan and McFadyen (2000, 2012)
Epiblema strenuana (Walker) Order: Lepidoptera Family: Tortricidae	Australia, 1982	Bella and Marchese (2007), Dhileepan and McFadyen (2012), McFadyen (1985, 1992)
Listronotus setosipennis (Hustache) Order: Coleoptera Family: Curculionidae	Australia, 1982	Bella and Marchese (2007), Dhileepan and McFadyen (2012), McFadyen (1992), Wild *et al.* (1992)
	Australia, 1991	De Clerck-Floate (2013)
Platphalonidia mystica (Razowski & Becker) Order: Lepidoptera Family: Tortricidae	Australia, 1992	Bella and Marchese (2007) Dhileepan and McFadyen (2012), Griffiths and McFadyen (1993)
Puccinia abrupta Dietel & Holw. var. *partheniicola* (H.S. Jacks.) Parmelee Order: Pucciniomycetes Family: Pucciniales	Australia, 1991	Dhileepan and McFadyen (2012), Fauzi et al. (1999), Parker et al. (1994)
Puccinia xanthii Schwein. var. *parthenii-hysterophorae* Seier, H.C. Evans & Á. Romero Order: Pucciniomycetes Family: Pucciniales	Australia, 2000	Dhileepan (2013), Dhileepan et al. (2006), Dhileepan and McFadyen (2012)
	Republic of South Africa, 2010	King (2000), Strathie (2012, 2013), Strathie et al. (2011)
Smicronyx lutulentus Dietz Order: Coleoptera Family: Curculionidae	Australia, 1981	Bella and Marchese (2007), Dhileepan and McFadyen (2012), McFadyen (1985, 1992), McFadyen and McClay (1981)
Stobaera concinna (Stål) Order: Hemiptera Family: Delphacidae	Australia, 1983	Dhileepan (2013), Dhileepan and McFadyen (2012), McFadyen (1985, 1992)
Zygogramma bicolorata Pallister Order: Coleoptera Family: Chrysomelidae	Australia, 1980	Bella and Marchese (2007), Dhileepan and McFadyen (2012), McFadyen (1985, 1992), McFadyen and McClay (1981)
	India, 1984	Dhileepan and Strathie (2009), Evans et al. (2000), Jayanth (1987), Kumar (1993)
	Sri Lanka, 2004	Dhileepan and Strathie (2009)

Puccinia abrupta Dietel & Holw. var. *partheniicola* (H.S. Jacks.) Parmelee Order: Pucciniomycetes Family: Pucciniales	Ethiopia, 1997	Dhileepan and Strathie (2009), Taye (2004)
	India, 1981	Dhileepan and Strathie (2009), Evans et al. (2000), Kumar et al. (2008), Kumar (1993)
	Kenya, 1977	Dhileepan and Strathie (2009), Day and Zalucki (2009), Taye (2004), Witt (2013), Wood and Scholler (2002)
	Mauritius, 1967	Dhileepan and Strathie (2009), Parmelee (1967), Wood and Scholler (2002)
	Nepal, 2011	Shrestha (2012), Shrestha et al. (2011)
	People's Republic of China, 2002	Dhileepan and Strathie (2009)
	Republic of South Africa, 1995	Dhileepan and Strathie (2009), Strathie (2013), Strathie et al. (2011), Wood (2013), Wood and Scholler (2002)
Zygogramma bicolorata Pallister Order: Coleoptera Family: Chrysomelidae	Nepal, 2009	Baars and Heystek (2003), Baars and Neser (1999), Shrestha et al. (2011)
	Pakistan, 2007	Dhileepan and Strathie (2009), Javid et al. (2007)

Parthenium has also been controlled by use of other biological control by competitive plant such as Cassia tora and marigold (Kumar and Viji, 2016).

Limitations of Biological control of *Parthenium*

The establishment of the biological control agent is the biggest drawback in success of the programme.

Biological Control of *Mikania micrantha*

Mikania micrantha is considered as one of the nastiest weed of tea (India and Indonesia) and rubber (Sri Lanka and Malaysia). *M. micrantha* has been a serious problem in the southern states and also in the northeastern states. This perennial climber has been known since 1918 and has been reported as a menace in many parts of Asia and Oceania. Many forests and agricultural crops are being suppressed owing to the prolific spread of *Mikania*. Numerous field crops (sugarcane, maize, rice, pineapple, cotton, coffee), forestry crops (teak, eucalypts) and agroforestry systems are under the grip of this invasive weed. Many insects have been reported to feed on *Mikania*. However, most of them are polyphagous and are of no use as biocontrol agents. Similarly indigenous pathogens were also found to be ineffective in controlling this weed, mainly due to their non-virulence. In India, attempts are being made to assess the potential of an exotic rust fungus, *Puccinia spegazzinii* against *Mikania.* This fungus is undergoing strict quarantine watch and several economically important agricultural and forestry crops are being screened.

An early but short-lived biological control program against Mikania using the thrips *Liothrips mikaniae* (Priesner) (Thysanoptera: Phlaeothripidae) was attempted in the 1980s in the Solomon Islands and Papua New Guinea (PNG).

Rust fungi *Puccinia spegazzinii* de Toni (Pucciniaceae) which occurs naturally and causes damage to *Mikania* in the neotropics, has great potential as a biocontrol agent against the weed (Sankaran *et al.*, 2008). Two butterflies *Actinote anteas* (Doubleday and Hewitson) and *A. thalia pyrrha* Fabricius (Lepidoptera: Nymphalidae) were used to control Mikania in Indonesia. Biological control agents for *Mikania micrantha* are given in table 4.

Table 3. *Biological Control Agents for Mikania micrantha*

Species Name of Agent	Country Established/ Found/ Year	Reference
Actinote anteas (Doubleday) Order: Lepidoptera Family: Nymphalidae	Indonesia, 1999	Day (2012), Desmier de Chenon *et al.* (2002), Zachariades *et al.* (2009)
Actinote thalia pyrrha Fabricius Order: Lepidoptera Family: Nymphalidae	Indonesia, 1999	Day (2012), Desmier de Chenon *et al.* (2002), Zachariades *et al.* (2009)
Liothrips mikaniae (Priesner) Order: Thysanoptera Family: Phlaeothripidae	Malaysia, 1990	Anwar (1996), Cock *et al.* (2000), Day (2012), Liau (1994)
	Solomon Islands, 1988	Cock *et al.* (2000), Day (2012), Vagalo (1992)
Puccinia spegazzinii De Toni Order: Pucciniomycetes Family: Pucciniales	Fiji, 2009	Day (2012, 2013), Day *et al.* (2013), Ellison and Day (2011)
	India, 2005	Ellison and Day (2011), Ellison *et al.* (2008), Sankaran (2008)
	Papua New Guinea, 2008	Day (2012, 2013), Day *et al.* (2013), Ellison and Day (2011)
	People's Republic of China, 2006	Day (2012), Ellison and Day (2011), Ellison (2013)
	People's Republic of China, 2011	Day (2013), Day *et al.* (2013)
	Taiwan, 2008	Day (2012, 2013), Ellison and Day (2011), Ellison (2013), Tzean (2013)
	Vanuatu, 2012	Day (2013), Day *et al.* (2013)

Limitations of Biological control of *Mikania*

The establishment of the biological control agent is the biggest drawback in success of the programme. The insect *Liothrips mikaniae* failed to establish in the Solomons while the laboratory culture died out in PNG (Sankaran *et al.* 2008).

Biological Control of *Prosopis juliflora*

In Africa already-established agents, *Algarobius prosopis* (LeConte) and *Neltumius arizonensis* (Schaeffer) (both Coleoptera: Chrysomelidae: Bruchinae), were used to control Prosopis species but were found inadequate to do so. Later other potential agents which included nine species of beetles four moth and a gall midge were utilized. Out of these a straight-snouted weevil, *Coelocephalapion gandolfoi* Kissinger (Coleoptera: Brentidae: Apioninae), whose larvae attack seeds within green pods, is considered especially promising. The biology, ecology and host range of a flower bud galler, *Asphondylia prosopidis* Cockerell (Diptera: Cecidomyiidae). Host range of these biological control agents has to be continuously monitored. Some pathogens have been considered, as either classical biological control agents or as Myco-herbicides (Zachariades *et al.*, 2011).

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Table 4. *Biological Control Agents for Prosopis juliflora*

Species Name of Agent	Country Established/ Found/ Year	Reference
Heteropsylla reducta Caldwell & Martorell Order: Hemiptera Family: Psyllidae	Ascension Island, 1997	Belton (2008), Fowler (1997, 2011)
Rhinocloa sp. Order: Hemiptera Family: Miridae	Ascension Island, 1997	Belton (2008), Fowler (1997, 2011, 2013)
Algarobius prosopis (Le Conte) Order: Coleoptera Family: Chrysomelidae	Botswana, 2012	Hoffman (2013)
	Egypt, 2001	Delobel and Fédière (2002), van Klinken *et al*. (2009)
	Namibia, 1988	Bethune *et al.* (2004), de Klerk (2004), Zimmermann (1991, 2013)
	Oman, 1985	Anton (1994), van Klinken *et al.* (2009)
	Saudi Arabia, 1980	Anton (1994), van Klinken *et al.* (2009)
	United Arab Emirates, 1983	Anton (1994), Baars and Neser (1999), van Klinken *et al.* (2009)
	Yemen, 1987	Ali and Labrada (2006), Anton (1994), van Harten (2013), van Klinken *et al.* (2009)

Neltumius arizonensis (Schaeffer) Order: Coleoptera Family: Chrysomelidae	Botswana, 2012	Hoffman (2013)
	Namibia, 2002	Bethune *et al.* (2004), de Klerk (2004), Zimmermann (2013)
Algarobius prosopis (Le Conte) Order: Coleoptera Family: Chrysomelidae	Ascension Island, 1997	Belton (2008), Fowler (1997, 2011, 2013), Jewsbury (2001), van Klinken *et al.* (2009), Akers (2006), Baars and Neser (1999), Zimmermann (1991)
Neltumius arizonensis (Schaeffer) Order: Coleoptera Family: Chrysomelidae	Ascension Island, 1997	Bella and Marchese (2007), Coetzer and Hoffmann (1997), Fowler (1997, 2013), van Klinken *et al.* (2009), White (2009)
Algarobius bottimeri Kingsolver Order: Coleoptera Family: Chrysomelidae	Australia, 1997	van Klinken (2012), van Klinken and Campbell (2009), Van Klinken and White (2008), Zimmermann (1991)
	Republic of South Africa, 1990	Impson *et al.* (1999), King (2000), Zachariades *et al.* (2011), Zimmermann (1991)
Algarobius prosopis (Le Conte) Order: Coleoptera Family: Chrysomelidae	Australia, 1996	van Klinken (2012), van Klinken and Campbell (2009), Van Klinken and White (2008), Zimmermann (1991)
	Republic of South Africa, 1987	Impson and Hoffmann (1998), Impson *et al.* (1999), King (2000), van Klinken et al. (2009), Zachariades et al. (2011), Zimmermann (1991)
Evippe sp. #1 Order: Lepidoptera Family: Gelechiidae	Australia, 1998	van Klinken (2012), van Klinken and Campbell (2009), van Klinken *et al.* (2003), van Klinken *et al.* (2009), Van Klinken and White (2008)
Neltumius arizonensis (Schaeffer) Order: Coleoptera Family: Chrysomelidae	Republic of South Africa, 1993	Coetzer and Hoffmann (1997), Impson *et al.* (1999), van Klinken *et al.* (2009), Zachariades *et al.* (2011)
Prosopidopsylla flava Burckhardt Order: Hemiptera Family: Psyllidae	Australia, 1998	van Klinken (2012, 2013), van Klinken and Campbell (2009), van Klinken *et al.* (2003), van Klinken *et al.* (2009)

CONCLUSION

Many biocontrol agents have been attempted in the past to control Invasive Alien Species (IAS) but so far, spectacular success could not be achieved to suppress or eradicate the IAS. So, extensive survey for indigenous natural enemies from different climate zones of India is required for effective management of invasive species. Further, integrated invasive alien species management efforts involving various experts will also provide an effective solution for management of IAS.

REFERENCES

Akers, R.P., C. Black, and M.J. Pitcairn. (2006). Biological control of water hyacinth III: above-freezing temperatures as a limiting factor in the effectiveness of the weevil *Neochetina bruchi*. In D.M. Woods, Ed. Biological Control Program (2005) Annual Summary. California Department of Food and Agriculture, Plant Health and Pest Prevention Services, Sacramento, California. 48-49 pp.

Ali, A.S. and Labrada, R. (2006). *Problems posed by Prosopis in Yemen. In Problems posed by the introduction of Prosopis spp. in selected countries* (FAO, Ed.). FAO, Rome. 21-28 pp.

Ananthakrishnan, T. N. (1992). Dimensions of insect plant Interactions. Intercept Ltd., New Delhi. 385 pp.

Anon. (1916). La lutte contre le *"Lantana mexicana"*. Journal Officiel des Establissements Français de l'Océanie 15 May: 263.

Anon. (1967). Commonwealth Institute of Biological Control. (1967). Annual Report for 1967. 99 pp.

Anon. (1968). Commonwealth Institute of Biological Control. (1968). Annual Report for 1968. 105 pp.

Anon. (1969). Commonwealth Institute of Biological Control. (1969). Annual Report for 1969. 107 pp.

Anon. (1969). Papua New Guinea Department of Agriculture Stock and Fisheries. Insect pest survey for the year ending 30th June, (1967). Papua New Guinea Agricultural Journal, 21: 49-75.

Anon. (1970). Commonwealth Institute of Biological Control. (1970). Annual Report for 1970. 115 pp.

Anon. (1971). Commonwealth Institute of Biological Control. Annual Report for 1971. 135 pp.

Anon. (1971). Papua New Guinea Department of Agriculture Stock and Fisheries. Insect pest survey for the year ending 30th June, (1968). Papua New Guinea Agricultural Journal, 22: 181-197.

Anon. (1972). Commonwealth Institute of Biological Control. Annual Report for 1972. 102 pp.

Anon. (1973). Commonwealth Institute of Biological Control. Annual Report for 1973. 52 pp.

Anon. (1974). Commonwealth Institute of Biological Control. Annual Report for 1974. 108 pp.

Anon. (1975). Commonwealth Institute of Biological Control. Annual Report for 1975. 106 pp.

Anon. (1976). Commonwealth Institute of Biological Control. Annual Report for 1976. 113 pp.

Anon. (2011). Land care Research Ltd. Gall-formers on black wattle: uninvited but welcome. What's New in Biological Control of Weeds?, 57: 3.

Anon. (2012). Biocontrol Agents and Host Plants in British Columbia. In *Invasive Plants with Biocontrol.* British Columbia Ministry of Forests, Lands, and Natural Resource Operations, 1 September 2012.

Anon. (2012). Landcare Research Ltd. Rusts to tackle one of the world's worst weeds. What's New in Biological Control of Weeds?, 59: 2-3.

Anon. (2013). HDOA Unpublished Records. Hawaii Department of Agriculture, Plant Pest Control Branch, 1428 S. King Street, Honolulu, Hawaii 96814 USA.

Anon. (1977-78). Commonwealth Institute of Biological Control. Annual Report for 1977-1978. 90 pp.

Anon. (1994). Beneficial organisms shipped by the SPC-German Biological Control Project during 1991-1993. SPC Agricultural News, 3: 17.

Anon. (2008). Landcare Research Ltd. Two possible shots at lantana. *What's New in Biological Control of Weeds?* 45(August 2008): 9.

Anton, K.W. (1994). The Bruchidae (Coleoptera) of Oman, with descriptions of a new genus and two new species. In *Fauna of Saudi Arabia (W. Buttiker and F. Krupp, Eds.). Vol. 14. pp. 105-112.*

Anwar, A.I. (1996). Biological control efforts towards the management of some common weeds in Malaysia. In S. Tjitrosemito and I. Soerianegara, Eds. Proceedings of the Symposium on Biology and Management of Weeds and 4th Tropical Weed Science Conference. 22-24 November 1994, Bogor, Indonesia; SEAMEO BIOTOP. pp. 149-157.

Baars, J.R. (2003). Geographic range, impact, and parasitism of lepidopteran species associated with the invasive weed *Lantana camara* in South Africa. Biological Control, 28(3): 293-301.

Baars, J.R. and F. Heystek. (2003). Geographical range and impact of five biocontrol agents established on *Lantana camara* in South Africa. Biocontrol, 48:743-749.

Baars, J.R. and S. Neser. (1999). Past and present initiatives on the biological control of *Lantana camara* (Verbenaceae) in South Africa. In Biological Control of Weeds in South Africa (1990-1998) (T. Olckers and M.P. Hill, Eds.). African Entomology Memoir, 1: 21-33.

Beeson, C.F.C. and Chatterjee, N.C. (1939). Possibilities of control of Lantana (*Lantana aculeata* L.) by indigenous insect pests. Indian Forest Records (New Series), 6:41-84.

Bella, S. and G. Marchese. (2007). First record of *Lantanophaga pusillidactylus* (Walker, 1864) for the Italian fauna *(Lepidoptera Pterophoridae)*. Bollettino di Zoologia Agraria e di Bachicoltura, 39(1):71-74.

Belton, T. (2008). Management strategy for Mexican thorn *(Prosopis juliflora)* on Ascension Island. Royal Society for the Protection of Birds, U.K. 23 pp.

Bennett P.H. and Vanstaden J. (1986). Gall formation in Crofton weed, *Eupatorium adenophorum* Spreng. (syn. *Ageratina adenophora*), by the *Eupatorium* gall fly *Procecidochares utilis* Stone (Diptera: Trypetidae). Australian Journal of Botany, 34: 473–480.

Bethune, S., M. Griffin, and D. Joubert. (2004). National review of invasive alien species in Namibia. Prepared for the Directorate of Environmental Affairs, Ministry of Environment and Tourism. Southern Africa Biodiversity Support Program, Windhoek, Namibia. 153 pp.

Bhumannavar, B.S. (2013). National Bureau of Agriculturally Important Insects, P.Bag No: 2491, H.A. Farm Post, Bellary Road, Bangalore - 560 024. Karnataka, India. *Source: Winston, et al. (2014)*

Bhumannavar, B.S., Ramani S., Rajeshwari S.K. (2007). Field release and impact of *Cecidochares connexa* (Macquart) (Diptera: Tephritidae) on *Chromolaena odorata* (L.) King and Robinson. Journal of Biological Control, 21(1):59-64.

Breniere, J. (1965). La lutte biologique a Madagascar. Congres de la Protection des Cultures Tropicales. Compte Rendus des Travaux, Marseilles 845-850. Source Winston, *et al.* (2014).

Broughton, S. (2000). Review and evaluation of lantana biocontrol programs. Biological Control, 17(3):272-286.

Bule, S. (2013). Biosecurity Vanuatu, Private Mail Bag 9095, Port Vila, Vanuatu. Source: Winston, et al. (2014)

Cilliers, C.J. (1977). On the biological control of *Lantana camara* in South Africa. In: *Proceeding: 2nd National Weeds Conference of South Africa*. 2-4 February 1977, Stellenbosch, South Africa; A.A. Balkema. 341-344pp.

Cilliers, C.J. (1983). The weed, *Lantana camara* L., and the insect natural enemies imported for its biological control into South Africa. Journal of the Entomological Society of South Africa, 46:131-138.

Cilliers, C.J. (1987a). The evaluation of three insect natural enemies for the biological control of the weed *Lantana camara* L. Journal of the Entomological Society of South Africa, 50:15-34.

Cilliers, C.J. (2013). Agricultural Research Council-Plant Protection Research Institute, Weeds Research, P/Bag X134, Queenswood, Pretoria 0121, South Africa.

Cilliers, C.J. and Neser, S. (1991). Biological control of *Lantana camara* (Verbenaceae) in South Africa. Agriculture, Ecosystems & Environment. Elsevier, 37 (1-3): 57-75.

Cochereau, P. and Mille, C. (2008). Weeds control in New Caledonia. In V. Blanfort and W. Orapa, Eds. Ecology, impact and management of invasives plant species in pastoral areas: Proceedings of the regional workshop on invasive plant species in pastoral areas. 24 to 28 November 2003, Koné, New Caledonia; *Secretariat of the Pacific Community.* 104-107pp.

Cock, M.J.W. (1986). Commonwealth Institute of Biological Control, Imperial College, Silwood Park, Ascot Berks SL5 7PY, United Kingdom. Source: Winston, et al. (2014)

Cock, M.J.W. and Godfray, H.C.J. (1985). Biological control of *Lantana camara* L. in the Philippines. Journal of Plant Protection in the Tropics, 2: 61-63.

Cock, M.J.W., Ellison, C.A., Evans, H.C. and Ooi, P.A.C. (2000). Can failure be turned into success for biological control of mile-a-minute weed *(Mikania micrantha)*? In N.R. Spencer, Ed. Proceedings of the X International Symposium on Biological Control of Weeds. 4-14 July 1999, Bozeman, Montana, USA; Montana State University. pp. 155-167.

Coetzer, W. and Hoffmann, J.H. (1997). Establishment of *Neltumius arizonensis* (Coleoptera: Bruchidae) on mesquite (Prosopis Species: Mimosaceae) in South Africa. Biological Control, 10: 187-192.

Conant, P. (2013). Hawaii Department of Agriculture, Plant Pest Control Branch, Hilo, Hawaii 96720 USA. Source: Winston, et al. (2014).

Conant, P., Garcia, J.N., Johnson, M.T., Nagamine, W.T., Hirayama, C.K., Markin, G.P. and Hill. R.L. (2013). Releases of natural enemies made in Hawaii since 1980 for classical biological control of weeds. *In: Proceedings of the XIII International Symposium on Biological Control of Weeds* (Y. Wu, T. Johnson, S. Sing, S. Raghu, G. Wheeler, P. Pratt, K. Warner, T. Center, J. Goolsby, and R. Reardon, Eds.). 11-16 September 2011, Kohala Coast, Hawaii, USA; Forest Health Technology Enterprise Team, Morgantown, WV, USA. 230-242 pp.

Davies, J.C. and Greathead, D.J. (1967). Occurrence of *Teleonemia scrupulosa on Sesamum indicum* Linn. in Uganda. Nature, 213: 102-03.

Davis, C. J. (1959). Recent introductions for biological control in Hawaii IV. *In: Proceedings of the Hawaiian Entomological Society,* 17(1): 62-66.

Davis, C.J. (1960). Recent introductions for biological control in Hawaii-- V. Hawaii. In*: Proceedings of the Entomological Society,* 17: 244-48.

Davis, C.J. (1970). Recent introductions for biological control in Hawaii XV. In: *Proceedings of the Hawaiian Entomological Society,* 20:521-525.

Davis, C.J. (1971). Recent introductions for biological control in Hawaii XVI. In: *Proceedings of the Hawaiian Entomological Society,* 21:59-62.

Davis, C.J. and Krauss, N.L.H. (1962a). Recent developments in the biological control of weed pests in Hawaii. In: *Proceedings of the Hawaiian Entomological Society,* 18: 65-67.

Davis, C.J. and Krauss, N.L.H. (1962b). Recent introductions for biological control in Hawaii VII. In: *Proceedings of the Hawaiian Entomological Society,* 18:125-129.

Davis, C.J. and Krauss, N.L.H. (1964). Recent introductions for biological control in Hawaii IX. In: *Proceedings of the Hawaiian Entomological Society,* 18: 391-397.

Davis, C.J. and Krauss, N.L.H. (1965). Recent introductions for biological control in Hawaii X. *Proceedings of the Hawaiian Entomological Society,* 19: 87-90.

Davis, C.J. and Krauss, N.L.H. (1966). Recent introductions for biological control in Hawaii XI. In: *Proceedings of the Hawaiian Entomological Society,* 19: 201-207.

Davis, C.J. and Krauss, N.L.H. (1967). Recent introductions for biological control in Hawaii XII. In: *Proceedings of the Hawaiian Entomological Society,* 19: 375-380.

Davis, C.J. and Krauss. (1963), N.L.H. Recent introductions for biological control in Hawaii VIII. In: *Proceedings of the Hawaiian Entomological Society,* 18: 245-249.

Davis, C.J., Yoshioka, E. and Kageler, D. (1992). *Biocontrol of Lantana camara, Opuntia* spp., and *Ageratina riparia* in Hawai'i: a review and update. Alien Plant Invasions in Native Ecosystems of Hawaii: *Management and Research* (C.P. Stone, C.W. Smith, and J.T. Tunison, Eds.). University of Hawaii Press, Honolulu, Hawaii. 2-32pp.

Day, M. D., Kawi, A. Kurika, K., Dewhurst, C. F., Waisale, S., Saul-Maora, J., Fidelis, J., Bokosou, J., Moxon, J., Orapa, W. and Senaratne, K.A.D. (2012). *Mikania micrantha* Kunth (Asteraceae) (Mile-a-Minute): Its Distribution and Physical and Socioeconomic Impacts in Papua New Guinea Pacific Science, 66(2): 213-223.

Day, M.D. (2012). *Lantana montevidensis* (Spreng.) Briq. - creeping lantana. *Biological Control of Weeds in Australia* (M. Julien, R. McFadyen, and J. Cullen, Eds.). CSIRO Publishing, Melbourne. 347-350pp.

Day, M.D. (2012). *Mikania micrantha* Kunth - mile-a-minute. Biological Control of Weeds in Australia (M. Julien, R. McFadyen, and J. Cullen, Eds.). CSIRO Publishing, Melbourne. 368-372pp.

Day, M.D. (2013). Department of Agriculture, Fisheries & Forestry, Ecosciences Precinct, GPO Box 267, Brisbane, Qld 4001, Australia. Source: Winston, *et al.* (2014)

Day, M.D. and McAndrew, T.D. (2002). Status of *Charidotis pygmaea* (Coleoptera: Chrysomelidae) as a biological control agent of *Lantana montevidensis* (Verbenaceae) in Australia. Biological Control, 23:27-34.

Day, M.D. and McFadyen, R.E.C. (2012). *Chromolaena odorata* (L.) Kind and Robinson - chromolaena. *Biological Control of Weeds in Australia* (M. Julien, R. McFadyen, and J. Cullen, Eds.). CSIRO Publishing, Melbourne. 162-169 pp.

Day, M.D. and Zalucki, M.P. (2009). *Lantana camara* Linn. (Verbenaceae). *Biological Control of Tropical Weeds using Arthropods* (R. Muniappan, G.V.P. Reddy, and A. Raman, Eds.). Cambridge University Press, Cambridge, UK. 211-246pp.

Day, M.D., Kawi, A.P., Fidelis, J., Tunabuna, A., Orapa, W., Swamy, B., Ratutini, J., Saul-Maora, J. and Dewhurst, C.F. (2013). Biology, field release and monitoring of the rust *Puccinia spegazzinii* de Toni (Pucciniales: Pucciniaceae), a biocontrol agent of *Mikania micrantha* Kunth (Asteraceae) in Papua New Guinea and Fiji. In: *Proceedings of the XIII International Symposium on Biological Control of Weeds* (Y. Wu, T. Johnson, S. Sing, S. Raghu, G. Wheeler, P. Pratt, K. Warner, T. Center, J. Goolsby, and R. Reardon, Eds.). 11-16 September 2011, Kohala Coast, Hawaii, USA; Forest Health Technology Enterprise Team, Morgantown, WV, USA. 211-217pp.

Day, M.D., Riding, N. and Chamberlain, A. (2009). Biology and host range of *Ophiomyia camarae* Spencer (Diptera: Agromyzidae), a potential biocontrol agent for Lantana spp. (Verbenaceae) in Australia. Biocontrol Science and Technology, 19(6): 627-637.

Day, M.D., S. Broughton, and M.A. Hannan-Jones. (2003). Current distribution and status of Lantana camara and its biological control agents in Australia, with recommendations for further biocontrol introduction into other countries. Biocontrol News and Information, 24(3):63N-76N.

Day, M.D., Wiley, C.J., Playford, J. and Zalucki, M.P. (2003). *Lantana*: Current Management Status and Future Prospects. Australian Centre for International Agriculture Research, Canberra. 128 pp.

Day, M.D., Willson, B.W. and Latimer, K.J. (1998). The life history and host range of *Ectaga garcia*, a biological control agent for *Lantana camara* and L. montevidensis in Australia. Biocontrol, 43(3):325-338.

De Clerck-Floate, R.A. (2013). Agriculture and Agri-Food Canada, Weed Biocontrol, Lethbridge Research Centre, 5403 1 Ave S, Lethbridge, Alberta, Canada T1J 4B1.

De Klerk, J. (2004). Bush encroachment in Namibia. Report on Phase 1 of the Bush Encroachment, Research, Monitoring and Management Project. Ministry of Environment and Tourism, Government of the Republic of Namibia. 273 pp.

De Wit M.P., Crookes, D.J., Van Wilgen, B.W., (2001). Conflicts of interest in environmental management: estimating the costs and benefits of a tree invasion. Biological Invasions, 3:167-178.

DeBach, P. (1964). The scope of biological control. In: *Biological Control of Insect Pests and Weeds* (P. DeBach Eds.). Reinhold, New York. 1-20pp.

Delobel, A. and Fédière, G. (2002). First report in Egypt of two seed-beetles (Coleoptera: Bruchidae) noxious to *Prosopis* spp. Bulletin of Faculty of Agriculture, Cairo University, 53(1):129-139.

Den Breeÿen, A. (2004). Release strategies for the establishment of the leaf spot pathogen, *Mycovellosiella lantanae* var. lantanae, on *Lantana camara* in South Africa. In: *Proceedings of the XI International Symposium on Biological Control of Weeds* (J.M. Cullen, D.T. Briese, D.J. Kriticos, W.M. Lonsdale, L. Morin, and J.K. Scott, Eds.). 17 April-2 May 2003, Canberra, Australia; CSIRO Entomology. 386-388 pp.

Den Breeÿen, A., and M.J. Morris. (2003). Pathogenicity and host specificity of *Mycovellosiella lantanae* var. lantanae, a potential biocontrol agent for *Lantana camara* in South Africa. Biocontrol Science and Technology, 13(3): 313-322.

Dennill, G.B., Donnelly, D., Stewart, K. and Impson, F.A.C. (1999). Insect agents used for the biological control of Australian Acacia species and Paraserianthes lophantha (Willd.) Nielsen (Fabaceae) in South Africa. *Biological Control of Weeds in South Africa (1990-1998)* (T. Olckers and M.P. Hill, Eds.). African Entomology Memoir, 1: 45-54

Denton, G.R.W., Muniappan, R. and Marutani, M. (1991a). The distribution and biological control of *Lantana camara* in Micronesia. Micronesica Supplement, 3:71-81.

Denton, G.R.W., Muniappan, R. and Marutani, M. (1991b). Status and natural enemies of the weed, *Lantana camara*, in Micronesia. Tropical Pest Management, 37:338-344.

Desmier de Chenon, R., Sipayung, A. and Sudharto, P. (2002). Impact of *Cecidochares connexa on Chromolaena odorata* in different habitats in Indonesia. In: *Proceedings of the 5th International Workshop on Biological Control and Management of Chromolaena odorata* (C. Zachariades, R. Muniappan, and L.W. Strathie, Eds.). 23 - 25 October 2000, Durban, South Africa; Agricultural Research Council-Plant Protection Research Institute.152pp.

Dhileepan, K. (2001). Effectiveness of introduced biocontrol insects on the weed *Parthenium hysterophorus* (Asteraceae) in Australia. Bulletin of entomological research, 91(3): 167-76.

Dhileepan, K. (2003). Seasonal variation in the effectiveness of the leaf-feeding beetle *Zygogramma bicolorata* (Coleoptera: Chrysomelidae) and stem-galling moth *Epiblema strenuana* (Lepidoptera: Tortricidae) as biocontrol agents on the weed *Parthenium hysterophorus* (Asteraceae). Bulletin of entomological research, 93(5): 393-401.

Dhileepan, K. (2009). Managing *Parthenium hysterophorus* across landscapes: limitations and prospects. *Management of Invasive Weeds* (Inderjit, S. Ed.). Invading Nature Springer Series in Invasion Ecology, Springer Science, Knoxville, 5:227-260.

Dhileepan, K. (2012). Widespread establishment and the spreading of the Carmenta moth; a biological control agent for parthenium weed in Queensland, Australia. International Parthenium News, 6:9.

Dhileepan, K. (2013). Department of Agriculture, Fisheries & Forestry, Ecosciences Precinct, GPO Box 267, Brisbane, Qld 4001 Australia.

Dhileepan, K. and McFadyen, R.C. (2012). *Parthenium hysterophorus* L. parthenium. *Biological Control of Weeds in Australia* (M. Julien, R. McFadyen, and J. Cullen, Eds.). CSIRO Publishing, Melbourne. 448-462 pp.

Dhileepan, K. and McFadyen, R.E. (1997). Biological control of Parthenium in Australia: progress and prospects. In: *Proceedings first International Conference on Parthenium Management.* 6-8 October 1997. Dharwad (Karnataka), I :40-44.

Dhileepan, K. and Strathie, L. (2009). *Parthenium hysterophorus* L. (Asteraceae). In *Biological Control of Tropical Weeds using Arthropods* (Muniappan, R., Reddy, G.V.P. and Raman, A. Eds.). Cambridge University Press, Cambridge, U.K. 274-318 pp.

Distant, W.L. (1907). Description of a new species of Tingididae from Honolulu. Entomologist, 404: 60-61.

Ellison, C. and Day, M. (2011). Current status of releases of *Puccinia spegazzinii* for *Mikania micrantha* control. Biocontrol News and Information, 32(1):1N-8N.

Ellison, C.A. (2013). CABI, Bakeham Lane, Egham, Surrey, TW20 9TY, United Kingdom.

Ellison, C.A., Evans, H.C., Djeddour, D.H. and Thomas, S.E. (2008). Biology and host range of the rust fungus *Puccinia spegazzinii:* A new classical biological control agent for the invasive, alien weed *Mikania micrantha* in Asia. Biological Control, 45:133-145.

Evans, H.C. (1997). *Parthenium hysterophorus:* a review of its weed status and the possibilities for biological control. Biocontrol News Information, 18:89N-98N.

Evans, H.C., Swier, M., Harvey, J., Djeddour, D., Aneja, K.R., Doraiswamy, S., Kauraw, L.P., Singh, S.P. and Kumar, P.S. (2000). Developing strategies for the control of parthenium weed in India using fungal pathogens. RNRRS Project Final Technical Report. NRIL Contract code: ZA0007/87, NRRD Project code: R6695. Natural Resources International, Crop Protection Programme. 191 pp.

Fauzi, M.T., Tomley, A.J., Dart, P.J., Ogle, H.J. and Adkins, S.W. (1999). The rust *Puccinia abrupta* var. *partheniicola, a potential* biological agent of Parthenium weed: environmental requirements for disease progress. Biological Control, 14:141-145.

Fowler, S.V. (1997). CAB International Institute of Biological Control, Silwood Park, Ascot, Berks SL5 7TA, United Kingdom. Source: Winston, *et al.* (2014)

Fowler, S.V. (2011). Weed bio control on Ascension Island. Ascension Conservation Quarterly, 36:16-21.

Fowler, S.V. (2013). Land Care Research, Biodiversity and Conservation, P.O. Box 69040, Lincoln 7640 New Zealand.

Fowler, S.V., Ganeshan, S., Mauremootoo, J. and Mungroo, Y. (2000). Biological control of weeds in Mauritius: past successes revisited and present challenges. In *Proceedings of the X International Symposium on Biological Control of Weeds* (N.R. Spencer, Ed.). 4-14 July 1999, Bozeman, Montana, USA; Montana State University. 43-50pp.

Fyfe, R.V. (1935). The lantana bug in Fiji. Agricultural Journal of Fiji, 8: 35-36.

Gardner, D.E. and Davis, C.J. (1982). The prospects for biological control of nonnative plants in Hawaiian National Parks. Technical Report 45. Cooperative Agreement No. CX 8000 2 000. University of Hawaii at Manoa, Honolulu, Hawaii. 55 pp.

Gatimel, B. (2013). Southern Province, Department of Rural Development, BP. 2386 - 98 846 Nouméa cedex, Nouvelle-Calédonie. Source: Winston, *et al.* (2014)

Goeden, R.D. (1978). Biological control of weeds. In:*Introduced parasites and predators of arthropod pests and weeds.* (C.P. Clausen, Ed.). Agriculture Handbook 480. United States Department of Agriculture, Washington D.C. 357-545pp.

Greathead, D.J. (1968). Biological control of Lantana. A review and discussion of recent developments in East Africa. Pest Articles and News Summaries (PANS) 14C: 167-175.

Greathead, D.J. (1971). A review of biological control in the Ethiopian region. Technical Communication No. 5. Commonwealth Institute of Biological Control, Farnham Royal, England. 162 pp.

Griffiths, M. and McFadyen, R.E. (1993). Biology and host-specificity of *Platphalonidia mystica* (Lep.: Cochylidae) introduced into Queensland to biologically control *Parthenium hysterophorus* (Asteraceae). Entomophaga, 38: 131-137.

Gutierrez, J. and Forno, I.W. (1989). Introduction into New Caledonia of two hispine phytophages of lantana: *Octotoma scabripennis* and *Uroplata girardi* (Coleoptera, Chrysomelidae). Acta Oecologica, Oecologia Applicata, 10:19-29.

Hammes, C. and Putoa, R. (1986). Catalogue des Insectes et Acariens d'intérêt agricole en Polynésie française. Entomologie agricole. Notes et documents No. 02. Centre ORSTOM de Tahiti, Tahiti. 270 pp.

Harley, K.L.S. (1973). Biological control of Central and South American weeds in Australia. In: *Proceedings of the II International Symposium on Biological Control of Weeds* (P.H. Dunn, Ed.). 4-7 October 1971, Rome, Italy; CAB. 4-8pp.

Harley, K.L.S. (1974). Biological control of Lantana in Australia. In: *Proceedings of the III International Symposium on Biological Control of Weeds* (A.J. Wapshere, Ed.). September 1973, Montpellier, France; CAB. 23-29pp.

Harley, K.L.S. (1997). Commonwealth Scientific and Industrial Research Organisation, Division of Entomology, Long Pocket Laboratories, Private Bag No. 3, Indooroopilly, Queensland 4068, Australia. Source: Winston, *et al.* (2014)

Harley, K.L.S. and Kunimoto, R.K. (1969). Assessment of the suitability of *Plagiohammus spinipennis* (Thoms.) (Col., Cerambycidae) as an agent for control of weeds of the *genus Lantana* (Verbenaceae).II. Host specificity. Bulletin of Entomological Research 58:787-792.

Harley, K.L.S. and R.C. Kassulke. (1971). Tingidae for biological control of Lantana camara (Verbenaceae). Entomophaga, 16: 389-410.

Haseler, W.H. (1966). The status of insects introduced for the biological control of weeds in Queensland. Journal of the Entomological Society of Queensland, 5:1-4.

Hasler W. H. (1976). *Parthenium hysterophorus* L. in Australia, PANS, 22:4, 515-517.

Hayes, L. (2013). Land Care Research, Biodiversity and Conservation, P.O. Box 69040, Lincoln 7640 New Zealand. Source: Winston, *et al.* (2014)

Heystek, F. (2006). Laboratory and field host utilization by established biological control agents of *Lantana camara* L. in South Africa. Rhodes University, Grahamstown, South Africa. 167 pp.

Heystek, F. (2007). Adding pressure on lantana. Plant Protection News, 74: 12.

Heystek, F. (2013). Agricultural Research Council- Plant Protection Research Institute, Weeds Research, P/Bag X134, Queenswood, Pretoria 0121 South Africa.

Heystek, F. and Kistensamy, Y. (2009). Initial establishment of the lantana petiole gall weevil. Plant Protection News, 80: 9-10.

Heystek, F. and Olckers, T. (2004). Establishment and impact of *Falconia intermedia* (Hemiptera: Miridae) on *Lantana camara* (Verbenaceae) in South Africa. In: *Proceedings of the XI International Symposium on Biological Control of Weeds* (J.M. Cullen, D.T. Briese, D.J. Kriticos, W.M. Lonsdale, L. Morin, and J.K. Scott, Eds.). 17 April-2 May 2003, Canberra, Australia; CSIRO Entomology. 606pp.

Hoffman, J.H. (2013). University of Cape Town, Department of Biological Sciences, Rondebosch, 7701, South Africa.

Impson, F.A.C. and J.H. Hoffmann. (1998). Competitive interactions between larvae of three bruchid species (Coleoptera) in mesquite seeds (*Prosopis* spp.) under laboratory conditions. African Entomology, 6(2): 376-378.

Impson, F.A.C., Kleinjan, C.A., Hoffmann, J.H., Post, J.A., and Wood, A.R. (2011). Biological control of Australian *Acacia species* and *Paraserianthes lophantha* (Willd.) Nielsen (Mimosaceae) in South Africa. African Entomology, 19(2):186-207.

Impson, F.A.C., Moran, V.C. and Hoffmann, J.H. (1999). A review of the effectiveness of seed-feeding bruchid beetles in the biological control of mesquite, Prosopis species (Fabaceae), in South Africa. In: Olckers, T. & Hill, M.P. (Eds). *Biological Control of Weeds in South Africa (1990–1998).* African Entomology Memoir, 1: 81–88.

Impson, F.A.C., Post, J.A., Hoffmann, J.H., (2013). Impact of the flower-galling midge, *Dasineura rubiformis* Kolesik, on the growth of its host plant, *Acacia mearnsii* De Wild, in South Africa. South African Journal of Botany, 87:118-121.

Impson, FAC, Kleinjan C.A, Hoffmann J.H., Post, J.A., (2008). *Dasineura rubiformis* (Diptera: Cecidomyiidae), a new biological control agent for *Acacia mearnsii* in South Africa. South African Journal of Science, 104(7/8):247-248.

ISSG, (2007). Global Invasive Species Database (GISD). Invasive Species Specialist Group of the IUCN Species Survival Commission.

Javaid, A., Shafique, S. and Shafique, S. (2007). Causes of rapid spread of Parthenium hysterophorus L. in Pakistan and possible control measures - a review. Pakistan Journal of Botany, 39(7): 2611-2618.

Jayanth, K.P. (1987). Introduction and establishment of Zygogramma bicolorata on *Parthenium hysterophorus* at Bangalore, India. Current Science, 56:310-311.

Jayanth, K.P. (1987). Introduction and establishment of *Zygogramma bicolorata* on *Parthenium hysterophorus* at Bangalore, India. Current Science, 40:568-569.

Jayanth, K.P. (1996). Biological control of aquatic weeds in India-progress and prospect, 122-129. In: *Aquatic Weed-Problem and Management"* (Ed. Varma, CVJ).Proceedings of Workshop on held at Bangalore (Karnataka), 5-7 June 1996.

Jewsbury, N. (2001). *Assessing the effectiveness of the biological control 'Mexican thorn', Prosopis juliflora, via the introductions of two seed feeding bruchids, on Ascension Island.* Kingston University, London, England.

Joseph, P.T. (1972). Department of Agriculture, Plant Protection, Government of the Cook Islands, Rarotonga, Cook Islands. Source: Winston, et al. (2014).

Joshi, S. (1991). Biological control of *Parthenium hysterophorus* L. (Asteraceae) by *Cassia uniflora* Mill (Leguminosae), in Bangalore, India. Tropical Pest Management, 37 (2): 182-184.

Joy, P.J, Satheesan, N.V., Lyla, K.R. and Joseph, D. (1985). Successful biological control of the floating weed *Salvinia molesta,* using the weevil, *Cyrtobagous salviniae*. Paper presented at the Asian–Pacific Weed Science Society, Chiang Mai, Thailand.

Julien, M.H. and Griffiths, M.W. (1998). Biological Control of Weeds: a World Catalogue of Agents and Their Target Weeds. CAB International Publishing, Wallingford, U.K.

Kairo, M. (1998). CABI Bioscience, Caribbean and Latin American Centre, Gordon St, Curepe, Trinidad and Tobago, West Indies. Source: Winston, et al. (2014)

Kamath, M.K. (1979). A review of biological control of insect pests and noxious weeds in Fiji 1969-1978. Agricultural Journal of Fiji, 41: 55-72.

Kermack, J. (1928). Action taken in regard to control of noxious weeds. *Fiji* Agricultural *Journal,* 1: 9-10.

Khan, A.H. (1944). On the Lantana bug (Teleonema scrupulosa Stal.). *Indian Journal of Entomology,* 6:149-161.

King, G.E. (2000). Contribution to knowledge on the family Pterophoridae in Spain: *Lantanophaga pusillidactyla* (Walker, 1864) a new species for Spain and for Europe (Lepidoptera: Pterophoridae). SHILAP Revista de Lepidopterologia, 28(111):341-343.

Klein, H. (2013). Agricultural Research Council-Plant Protection Research Institute, Weeds Research, P/Bag X134, Queenswood, Pretoria 0121 South Africa. Source: Winston, *et al.* (2014).

Krauss, N.L.H. (1962). Biological control investigations on lantana.

Krauss, N.L.H. (1962a) Biological control investigations on insect, snail, and weed pests in Tropical America. 1961. *Hawaii. Ent. Soc. Proc. 18 (1961)*: 132-33.

Krauss, N.L.H. (1962b) Biological control investigations on Lantana. *Hawaii. Ent. Soc. Proc. 18: 134-36.*

Kumar S. and Saraswat V.N. (2001). Integrated management: The only solution to suppress *Parthenium hysterophorus,* pp.150-168. In: Alien Weeds in Moist Tropical Zones: Banes and Benefits, (Eds. KV Sankaran, ST Murphy and HC Evans) Workshop Proceedings, 2-4 November, 1999, Kerala Forest Research Institute, India and CABI Bioscience, UK Centre (Ascot), UK.

Kumar, R. and Viji. (2016). Biological Control of Parthenium. Directorate of Weed Research, Jabalpur.

Kumar, S. (1993). Biological control of problematic weeds of forests and wastelands in India. Annals of Entomology, 11: 79-97

Kumar, S. (1993). Biological control of problematic weeds of forests and wastelands in India. Annals of Entomology, 11: 79-97

Kumar, S. (2005). Biological control of Parthenium through *Zygogramma bicolorata.* National Research Centre for Weed Science, Jabalpur, India, 88 pp.

Kumar, S. (2006). Economic benefits in biological control of Parthenium by Mexican beetle, *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae) in India. Annals of Entomology, 24(1&2):75-78.

Kumar, S. (2009). Biological control of *Parthenium* in India: status and prospects. Indian Journal of Weed Science, 41(1&2):1-18.

Kumar, S. (2011). Aquatic weeds problems and management in India. Indian Journal of Weed Science, 43(3&4):118-138.

Kumar, S. (2012). Current spread, impact and management of Parthenium weed in India. International Parthenium News, 5: 1-6.

Kumar, S. (2013). Weed problems in protected areas and prospects of their management, pp. 105-116. In: Protected Areas in India: Prospects and Retrospect. In: *Proceedings of National Workshop on Grassland Management.* Bandhavgarh Tiger Reserve, Madhya Pradesh, 4-6 July 2013, Organized by State forest Research Institute, Jabalpur.

Kumar, S. and Bhan, V.M. (1996). Parthenium control by insects in India: retrospect and prospects. Journal of Applied Zoological Researches, 6(2):109-115.

Kumar, S. and Ray P. (2011). Evaluation of augmentative release of *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae) for biological control of *Parthenium hysterophorus* L. Crop Protection, 30:587-591.

Kumar, S. and Ray P., (2010). Activity enhancement of Zygogramma bicolorata, a biocontrol agent of Parthenium hysterophorus, by temperature regulated diapause aversion. Biocontrol Science and Technology, 20(9):903-908.

Kumar, S. and Varsheny J. G. (2007). Gajar Ghas ka jaivik Niyantrana: Vartman sthathi avamn sambhavnayn (in Hindi) [Biological Control of Parthenium: Present Situation and Prospects]. National Research Centre for Weed Science: 157 pp.

Kumar, S. and Varshney J.G. (2010). Parthenium infestation and its estimated cost management in India. Indian Journal of Weed Science, 42(1&2):73-77.

Lal, S.N. (1997). Ministry of Agriculture, Fisheries, Forests and ALTA, Koronovia Research Station, P.O. Box 77, Nausori, Fiji. Source: Winston, *et al.* (2014).

Lennox, C.L., Morris, M.J. and Wood, A.R. (2000). Stumpout – commercial production of a fungal inoculant to prevent regrowth of cut wattle stumps in South Africa. In N.R. Spencer, Ed. *Proceedings of the X International Symposium on Biological Control of Weeds.* 4-14 July 1999, Bozeman, Montana, USA; Montana State University. 140pp.

Lever, R.J.A.W. (1938). Economic insects in some western Pacific Islands. Agricultural Journal of Fiji, 4:11-12.

Liau, S.S., Tan, C.L., Ooi, P.A.C., Chung, G.F., Lee, S.A. and Tay, B.L. (1994). Field releases of Liothrips mikaniae (Priesner) for the control of Mikania micrantha HBK- Experience in Malaysia. In: *Proceedings of the 4th International Conference on Plant Protection in the Tropics* (A. Rajan and Y.B. Ibrahim, Eds.). 28-31 March, 1994, Kuala Lumpur, Malaysia; Malaysian Plant Protection Society. 116-119pp.

Löyttyniemi, K. (1982). Evaluation of the use of insects for biological control of *Lantana camara* L. (Verbenaceae) in Zambia. Tropical Pest Management, 28(1): 14-19.

Mabuda, K. (2005). *Eutreta xanthochaeta* (Diptera: Tephritidae) is unsuitable for biocontrol of *Lantana camara* in Africa. Biocontrol Science and Technology, 15(6): 635-639.

Maheshwari, J.K. (1966). *Parthenium hysterophorus*. Current Science, 35:181-183.

Manian, S. and Shanmughavel, P. (2003). Biocontrol of *Lantana camara*. The Hindu. Thursday, Dec 18. Online version.

Manners, A.G., Palmer, W.A., Burgos, A., McCarthy, J., and Walter, G.H. (2011). Relative host plant species use by the lantana biological control agent *Aconophora compressa* (Membracidae) across its native and introduced ranges. Biological Control, 58: 262-270.

Matsunaga, J.N. (2013). Hawaii Department of Agriculture, Plant Pest Control Branch, 1428 S. King Street, Honolulu, Hawaii 96814 USA. Source: Winston, *et al.* (2014)

McClay, A.S., McFadyen, R.E. and Bradley, J.D. (1990). Biology of *Bucculatrix parthenica* Bradley sp. n. (Lepidoptera: Bucculatricidae) and its establishment in Australia as a biological control agent for *Parthenium hysterophorus* (Asteraceae). Bulletin of Entomological Research, 80(4): 427-432.

McConnachie, A.J. (2013). Agricultural Research Council-Plant Protection Research Institute, Weeds Research, P/Bag 6006, Hilton 3245 South Africa. Source: Winston, et al. (2014)

McFadyan, RE. (1985). The biological control programme against *Parthenium hysterophorus* in Queensland. In: *Proceedings of the Sixth International Symposium on Biological Control of Weeds, (Eds. ES Delfosse). Ottawa, Canada : 789-796,*

McFadyen, R.C. (1992). Biological control against parthenium weed in Australia. Crop Protection, 11:400-407.

McFadyen, R.E. and McClay, A.S. (1981). Two new insects for the biological control of *Parthenium* in Queensland. In: *Proceedings of the 6th Australian Weeds Conference* (B.J. Wilson and J.T. Swarbrick, Eds.).13-18 September 1981, Gold Coast, Queensland, Australia; Queensland Weed Science Society. 145-149pp.

Meyer, J.Y. (2013). Délégation à la Recherche, Gouvernement de la Polynésie Française B.P. 20981 Papeete, Tahiti. Source: Winston, et al. (2014)

Mishra, S.C. and Sen, S.P.K. (1986). Host specificity test and note on life history of *Leptobyrsa decora* Drake (Hemiptera: Tingidae) on teak. Bulletin of Entomology, 27: 81-86.

Morris, M.J., Wood, A. and Den Breeÿen, A. (1999). Plant pathogens and biological control of weeds in South Africa: a review of projects and progress during the last decade. I*n: Biological Control of Weeds in South Africa* (T. Olckers and M.P. Hill, Eds.). African Entomology Memoir, 1:129-137.

Muniappan, R. (1988). Biological control of the weed, *Lantana camara* in Guam. Journal of Plant Protection in the Tropics, 5:99-101.

Muniappan, R. (2013). Virginia Tech, IPM IL (CRSP), 526 Prices Fork Road, Blacksburg, VA 24061 USA. Source: Winston, *et al.* (2014).

Muniappan, R. and Reddy, G.V.P. (2003). Fortuitous introduction of two natural enemies of *Lantana camara* to Chuuk. In: *Proceedings of the Hawaiian Entomological Society,* 36: 123-124.

Muniappan, R. and Viraktamath, C.A. (1986). Status of biological control of the weed, *Lantana camara* in India. Tropical Pest Management, 32: 40-42.

Myers, J.H. (2000). What Can we learn from biological Control Failures ? Proceedings of the X International Symposium on Biological Control of Weeds 151, 4-14 July 1999, Montana State University, Bozeman, Montana, USA. Neal R. Spencer [ed.]. pp. 151-154.

Nafus, D. and Schreiner, I. (1989). Biological control activities in the Mariana Islands from 1911 to 1988. Micronesica, 22:65-106.

Neser, S. (1998). Agricultural Research Council, Plant Protection Research Institute, Private Bag X134, Pretoria 0001, Republic of South Africa. Source: Winston, *et al.* (2014).

Neser, S. and Annecke, D.P. (1973). Biological control of weeds in South Africa. Entomology Memoir, 28: 1-27.

Nishida, G.M. (2008a). French Polynesia bug checklist (preliminary). Version 19 November 2008.

Nishida, G.M. (2008b). French Polynesia fly checklist (preliminary). Version 13 November 2008. http://essigdb.berkeley.edu/checklists/fpDiptera.doc.31 March 2013.

O’Connor, B.A. (1950). Biological control of insects and plants in Fiji. Agricultural Journal of Fiji 21: 43-54.

Oishi, D.E. (2011). Hawaii Department of Agriculture, Plant Pest Control Branch, 1428 S. King Street, Honolulu, Hawaii 96814 USA. Source: Winston, *et al.* (2014)

Oosthuizen, M.J. (1964). The biological control of *Lantana camara* L. in Natal. Journal of the Entomological Society of South Africa, 27:3-16.

Orapa, W. (2005). Biological control of weeds in Papua New Guinea. In: *Proceedings of the 20th Asian-Pacific Weed Sciences Society Conference.* 7-11 November 2005, Ho Chi Min City, Vietnam. 457-465pp.

Orapa, W. (2013). National Agricultural Quarantine and Inspection Authority, PO Box 741, Port Moresby, NCD, Papua New Guinea. Source: Winston, *et al.* (2014).

Palmer, W.A., Heard, T.A. and Sheppard, A.W. (2010). A review of Australian classical biological control of weeds programs and research activities over the past 12 years. Biological Control, 52(3):271-287.

Palmer, W.A., Willson, B.W. and Pullen, K.R. (1996). The host range of *Aconophora compressa* Walker (Homoptera: Membracidae): a potential biological control agent for *Lantana camara* L. (Verbenaceae). In: *Proceedings of the Entomological Society of Washington,* 98: 617-624.

Parker, A., Holdern, A.N.G. and Tomley, A.J. (1994). Host specificity testing and assessment of the pathogenicity of the rust, *Puccinia abrupta* var. partheniicola, as a biological control agent of parthenium weed *(Parthenium hysterophorus)*. Plant Pathology, 43: 1-16.

Parmelee, J.A. (1967). The autoecious species of *Puccinia* on Heliantheae in North America. Canadian Journal of Botany, 45:2267-2340.

Pemberton, R.W. (2000). Predictable risk to native plants in weed biological control. Oecologia, 125(4): 489-494.

Perkins, R.C.L. and Swezey, O.H. (1924). The introduction into Hawaii of insects that attack lantana. Bulletin of the Hawaiian Sugar Plantation Association Experimental Station, 16:1-83.

Rabindra, J. and Bhumannavar, B. (2009). *Biological control of weeds in India. In: Biological Control of Tropical Weeds using Arthropods* (R. Muniappan, A. Raman, and G.V.P. Reddy, Eds). Cambridge University Press, Cambridge, U.K. 438-452 pp.

Radcliffe E. B.,W. D. Hutchison & R. E. Cancelado [eds.](2009), Radcliffe's IPM World Textbook, URL: https://ipmworld.umn.edu, University of Minnesota, St. Paul, MN.

Rao, A.N. and Chauhan, B.S. (2015). Weeds and Weed Management in India - *A Review. Weed-Science in the Asian-Pacific Region. Ch. 4: 87-112.*

Rao, R. (1920). Lantana insects in India. In Memoirs, Department of Agriculture in India. Entomology Series. India Imperial Department of Agriculture, Calcutta. 239-314pp.

Rao, V.P. (1971). *Biological control of pests in Fiji.* Miscellaneous Publication 2. Commonwealth Institute of Biological Control, Farnham Royal, England. 38 pp.

Rao, V.P., Ghani, M.A., Sankaran, T. and Mathur, K.C. (1971). A review of the biological control of insects and other pests in south-east Asia and the Pacific Region. Commonwealth Institute of Biological Control, 6: 1-149.

Sankaran, K.V., Ellison, Carol, A. and Prakya, S. K. (2008). Carol A Ellison Field release of the rust fungus Puccinia spegazzinii to control *Mikania micrantha* in India: protocols and raising awareness. XII International Symposium on Biological Control of Weeds.

Sankaran, K.V., Puzari, K.C., Ellison, C.A., Kumar, P.S. and Dev, U. (2008). Field release of the rust fungus *Puccinia spegazzinii* to control *Mikania micrantha* in India: protocols and awareness raising. In: *Proceedings of the XII International Symposium on Biological Control of Weeds* (M.H. Julien, R. Sforza, M.C. Bon, H.C. Evans, P.E. Hatcher, H.L. Hinz, and B.G. Rector, Eds.). 22-27 April 2007, La Grande Motte, France; CAB International.

Sankaran, T. (1973). Biological control of weeds in India. A review of introductions and current investigations of natural enemies. In P.H. Dunn, Ed. *Proceedings of the II International Symposium on Biological Control of Weeds.* 4-7 October 1971, Rome, Italy; CAB. pp. 82-88.

Sasakawa, M. (1963). A revision of Polynesian Agromyzidae (Diptera). Pacific Insects, 5(3): 489-506.

Sasakawa, M. (1963). Oriental Agromyzidae (Diptera) in Bishop Museum, Part 1. Pacific Insects, 5(1): 23-50.

Scheibelreiter, G.K. (1980). Biological control of *Lantana camara* L. (Verbenaceae) in Ghana. Zeitschrift für Angewandte Entomologie, 90: 99-103.

Schreiner, I. (1989). Biological control introductions in the Caroline and Marshall Islands. Proceedings of the Hawaiian Entomological Society, 29:57-69.

Shabbira, A., Dhileepan, K., Steve, B., and Chris O'Donnella Adkinsa, W. (2013). Complementing biological control with plant suppression: Implications for improved management of parthenium weed (*Parthenium hysterophorus* L.) Biological Control, 64(3): 270-275.

Shackleton, Ross T., Witt, Arne B,R., Winnifred, Aool and Corin F Pratt. (2017). Distribution of the invasive alien weed, *Lantana camara,* and its ecological and livelihood impacts in eastern Africa, African Journal of Range & Forage Science, 34:1, 1-11.

Shrestha, B.B. (2012). Parthenium research in Nepal: an update. International Parthenium News, 6: 6-8.

Shrestha, B.B., K.B. Thapa-Magar, A. Paudel, and U.B. Shrestha. (2011). Beetle on the battle: defoliation of *Parthenium hysterophorus* by *Zygogramma bicolorata* in Kathmandu valley, Nepal. Botanica Orientalis: Journal of Plant Science 8: 100-104.

Simelane, D. (2005). Biological control of *Lantana camara* in South Africa: targeting a different niche with a root-feeding agent, Longitarsus sp. Biocontrol, 50(2): 375-387.

Simelane, D.O. (2002). Biology and host range of Ophiomyia camarae, a biological control agent for Lantana camara in South Africa. Biocontrol, 47(5): 575-585.

Simelane, D.O. (2007). Influence of soil texture, moisture, and surface cracks on the performance of a root-feeding flea beetle, Longitarsus bethae (Coleoptera: Chrysomelidae), a biological control agent for *Lantana camara* (Verbenaceae). Environmental Entomology, 36(3): 512-517.

Simelane, D.O. (2010). Potential impact of an introduced root-feeding flea beetle, Longitarsus bethae, on the growth and reproduction of an invasive weed, *Lantana camara*. Biological Control, 54:114-118.

Simelane, D.O. and Phenye, M.S. (2004). Preliminary assessment of release and establishment of lantana herringbone leafminer, *Ophiomyia camarae* (Diptera: Agromyzidae), in South Africa. In: *Proceedings of the XI International Symposium on Biological Control of Weeds* (J.M. Cullen, D.T. Briese, D.J. Kriticos, W.M. Lonsdale, L. Morin, and J.K. Scott, Eds.). 17 April-2 May 2003, Canberra, Australia; CSIRO Entomology. 447-450pp.

Simelane, D.O. and Phenye, M.S. (2005). Suppression of growth and reproductive capacity of the weed *Lantana camara* (Verbenaceae) by *Ophiomyia camarae* (Diptera: Agromyzidae) and *Teleonemia scrupulosa* (Heteroptera: Tingidae). Biocontrol Science and Technology, 15:153-163.

Simmonds, F.J. (1967). Biological control of pests of veterinary importance. The Veterinary Bulletin, 37:71-85.

Simmonds, H.W. (1928). Lantana bug, *"Teleonemia lantanae* Distant". Agricultural Journal of Fiji, 1:16-21.

Simmonds, H.W. (1930). Entomological notes. Fiji Agricultural Journal, 3:82.

Simmonds, H.W. (1931). Noxious weeds and their control in Fiji. II. Biological control. Fiji Agricultural Journal, 4: 29-31.

Simmonds, H.W. (1932). A list of insects introduced into Fiji for the biological control of pests and weeds. Agricultural Journal of Fiji, 5: 5-9.

Simmonds, H.W. (1932). Biological control- progress report. Fiji Agricultural Journal, 5:21-22.

Simmonds, H.W. (1934). Biological control of noxious weeds with special reference to the plants *Clidemia hirta* (the curse) and *Stachytarpheta jamaicensis* (blue rat tail). Agricultural Journal of Fiji, 7: 3-10.

Singh, N.P. (1983). Potential biological control of *Parthenium hysterophorus* L. Current Science, 52:644.

Singh, S.P. (1989). Biological suppression of weeds. NCIPM, Faridabad: Technical Bulletin, No.1. 15-16pp.

Singh, S.P. (1997). Perspectives in biological control of Parthenium in India. In: *Proceedings of First International Conference on Parthenium held at Dharwad (Karnataka),* 6-8 October 1997, (Eds. M. Mahadevappa and V.C. Patil), Volume I : 22-32.

Singh, S.P. (1998). A review of biological suppression of *Chromolaena odorata* K & R in India. In: *Proceedings of 4th international workshop on biological control and management of Chromolaena odorata,* (Fessar *et al.*, Eds.). 86-92pp. USA, University of Guam.

Singh, S.P. (2001). Biological control of invasive weeds in India. In: *Proceedings of the Workshop on Alien Weeds in Moist Tropical Zones: Banes and Benefits* Sankaran, (K.V., Murphy, S.T. and Evans, H.C. Eds). Kerala Forest Research Institute, India and CABI Bioscience UK Centre (Ascot), UK, 11-19 pp.

Singh, SP. (1989). Biological suppression of weeds. NCIPM, Faridabad: Technical Bulletin No.1:15-16.

Smith, L., E. de Lillo, and Amrine, J.W.Jr. (2010). Effectiveness of eriophyid mites for biological control of weedy plants and challenges for future research. Experimental and Applied Acarology, 51(1):115-149.

Spencer, K.A. (1962). Some Agromyzidae (Diptera) from New Guinea, Melanesia, and Polynesia. Pacific Insects, 43(3): 651-660.

Spencer, K.A. (1973). Agromyzidae (Diptera) of Economic Importance. Dr. W. Junk, B.V., The Hague. 418 pp.

Strathie, L. (2012). Progress towards biological control of parthenium weed in South Africa. International Parthenium News, 6: 3-4.

Strathie, L.W. (2013). Agricultural Research Council-Plant Protection Research Institute, Weeds Research, P/Bag 6006, Hilton 3245 South Africa. Source: Winston, et al. (2014).

Strathie, L.W., McConnachie, A.J. and Retief, E. (2011). Initiation of biological control against *Parthenium hysterophorus* L. (Asteraceae) in South Africa. African Entomology, 19(2): 378-392.

Subramanian, T.V. (1934). The lantana seedfly in India, *Agromyza (Ophiomyia) lantanae* Froggatt. Indian Journal of Agricultural Science, 4: 468-471.

Sushil, K. (2005). Biological control of Parthenium through *Zygogramma bicolorata.* National Research Centre for Weed Science, Jabalpur, India, 88 pp.

Sushil, K. (2009). Biological control of *Parthenium* in India: status and prospects. Indian Journal of Weed Science, 41(1&2):1-18.

Sushil, K. (2011). Aquatic weeds problems and management in India. Indian Journal of Weed Science, 43(3&4):118-138.

Sushil, K.(1993). Biological control of forests and waste land weeds in India. Annals of Entomology, 11(2):131-153.

Sushilkumar and Bhan, V.M. (1995). Parthenium control by insects in India: retrospecs and Prospects. Journal of Applied Zoological Research, 6:109-112.

Sushilkumar. (1993). Biological (insect) control of problematic weeds of forests and waste lands in India. Annals of Entomology, 11(2):79-97.

Swaminathan, S. and Raman, A. (1981). On the morphology of the stem-galls of *Eupatorium adenophorum* Spreng. (Compositae) and the natural enemies of the cecidozoan, *Procecidochares utilis* Stone (Tephritidae, Diptera). Current Science, 50: 294-295.

Swarbrick, J.T. and Donaldson, J.F. (1991). Host range studies with the Lantana mealybug (*Phenacoccus parvus* Morrison). Plant Protection Quarterly, 6: 68-69.

Swezey, O.H. (1923). Records of introduction of beneficial insects into the Hawaiian Islands. In: *Proceedings of the Hawaiian Entomological Society,* 5: 299-304.

Szent-Ivany, J.J.H. (1964). Pacific Entomology. Report of the Standing Committee Chairman. University of Hawaii Press, Honolulu, Hawaii. 93 pp.

Taye, T., Einhorn, G., Gossmann, M., Buttner, C. and Metz., R. (2004). The potential of parthenium rust as biological control of parthenium weed in Ethiopia Pest Management. Journal of Ethiopia, 8: 39-50.

Taylor, E.E. (1989). A history of biological control of *Lantana camara* in New South Wales. Plant Protection Quarterly, 4:61-65.

Taylor, S., Kumar, L., Reid, N., and Kriticos, D. J. (2012). Climate Change and the Potential Distribution of an Invasive Shrub, *Lantana camara* L. PLoS ONE, 7(4):1-14.

Thakur, M.L., Anmad, A. and Thakur, R.K. (1992). Lantana weed *Lantana camara* var. *aculeata* Linn and its possible management through natural insect-pests in India. Indian Forester, 118(7): 466-488.

Tomley, A.J. and Riding, N. (2002). *Prospodium tuberculatum,* lantana rust, a new agent released for the biocontrol of the woody shrub *Lantana camara. In: Proceedings of the 13th Australian Weeds Conference (J.H. Spafford, J. Dodd, and J.H. Moore, Eds.).* 8-13 September 2002, Perth, Western Australia; Plant Protection Society of WA. 389-390 pp.

Trujillo, E. (1997). Classical biological control of weeds with pathogens. IBG News, 6(2): 11-13.

Trujillo, E.E. (2005a). Biological control of bush lantana and invasive weed of Hawaii's forest. Biological Control, 33(1): 113-122.

Trujillo, E.E. (2005b). History and success of plant pathogens for biological control of introduced weeds in Hawaii. Biological Control, 33:113-122.

Tryon, H. (1912). Insects for checking growth or dissemination of lantana. Queensland Agricultural Journal, 29: 493-498.

Tzean, S.S. (2013). Department of Plant Pathology & Microbiology - National Taiwan University No.1, Sec. 4, Roosevelt Road., Taipei, 10617, Taiwan. Source: Winston, et al. (2014).

Urban, A., D. Simelane, and Witt, A. (2010a). Lantana herringbone leafminer now in Ethiopia. Plant Protection News, 84: 9.

Urban, A., Simelane, D. and Strathie, L. (2010). Lantana herringbone leafminer now in Madagascar. Plant Protection News, 83: 14.

Urban, A.J. (2013). Agricultural Research Council-Plant Protection Research Institute, Weeds Research, P/Bag X134, Queenswood, Pretoria 0121 South Africa. Source: Winston, et al. (2014).

Urban, A.J., Simelane, D.O., Retief, E., Heystek, F., Williams, H.E. and Madire L.G. (2011). The invasive 'Lantana camara L.' hybrid complex (Verbenaceae): a review of research into its identity and biological control in South Africa. African Entomology, 19(2):315-348.

Vagalo, M. (1992). Ministry of Agriculture and Fisheries, Dodo Creek Research Station, PO Box G13, Honiara, Solomon Islands. Source: Winston, *et al.* (2014).

Van Harten, A. (1995). South Pacific Commission- German Biological Control Project, Private Mail Bag, Suva, Fiji. Source: Winston, *et al.* (2014).

Van Klinken, R.D. (2012). Prosopis spp. - mesquite. In *Biological Control of Weeds in Australia* (M. Julien, R. McFadyen, and J. Cullen, Eds.). CSIRO Publishing, Melbourne. 477-485pp.

Van Klinken, R.D. and A. White. (2008). Optimising management of core mesquite infestations in Australia. Program: Defeating the Weed Menace R & D. Final Report. Project number: CEN23. Product Code: PN22407. Australian Government Land & Water Australia, Canberra, Australia. 39 pp.

Van Klinken, R.D. and Campbell, S.D. (2009). Prosopis L. species. In F.D. Panetta, Ed. The Biology of Australian Weeds. Vol. 3. R.G. and F. J. Richardson, Melbourne. pp. 238-273.

Van Klinken, R.D., Hoffmann, J.H., Zimmermann, H.G. and Roberts, A.P. (2009). Prosopis species (Leguminosae).In: *Biological Control of Tropical Weeds using Arthropods* (Muniappan, R., Reddy, G.V.P., Raman, A. Eds). Cambridge University Press, Cambridge, U.K. 353–377pp.

Vivian-Smith, G., Gosper, C.R., Wilson, A., and Hoad, K. (2006). *Lantana camara* and the fruit- and seed-damaging fly, *Ophiomyia lantanae* (Agromyzidae): seed predator, recruitment promoter or dispersal disrupter?, Biological Control, 36(2): 247-257.

Wang, Y.S., Jaw, C.G. and Chen, Y.I. (1994). Accumulation of 2, 4-D and glyphosate in fish and water hyacinth. Water, Air and Soil Pollution, 74: 397 - 403.

Waterhouse, D.F. and Norris, K.R. (1987). Biological Control: Pacific Prospects. Inkata Press, Melbourne. 454 pp.

Weber, P.W. (1955). Recent liberations of beneficial insects in Hawaii - IV. In: *Proceedings of the Hawaiian Entomological Society,* 15: 635-638.

Weber, P.W. (1956). Recent introductions for biological control in Hawaii - XVI. In: *Proceedings of the Hawaiian Entomological Society,* 16: 162-164.

White, L. (2009). Survey of biocontrol agents of Mexican thorn *(Prosopis juliflora)* on Ascension Island. University of Exeter, Exeter, U.K. 75 pp. Witt, A. 2013. CABI, ICRAF Complex, United Nations Avenue, Gigiri, P.O. Box 633-00621, Nairobi, Kenya. Source: Winston, et al. (2014).

Wild, C.H., McFadyen, R.E., Tomley, A.J. and Willson, B.W. (1992). The biology and host specificity of the stem-boring weevil *Listronotus setosipennis* (Col: Curculionidae), a potential biocontrol agent for *Parthenium hysterophorus* (Asteraceae). Entomophaga, 37: 591-598.

Williams, D.J. and A.B. Hamon. (1994). Scientific Note: Phenacoccus parvus Morrison, a possible injurious mealybug recorded for the first time from Florida (Homoptera: Coccoidea: Pseudococcidae). Insecta Mundi Paper, 299:16.

Willson, B.W. (1979). The current status of biological control of rangeland weed projects in Australia. In: *Proceedings Australian Applied Entomological Research Conference, Invited Reviews and Situation Papers.* 11-15 June 1979, Lawes, Australia. 214-222pp.

Wilson, C.G. and Forno, I.W. (1995). The biological control programme against *Mimosa pigra* in Australia's Northern Territory. In: *Proceedings of the VIII International Symposium on Biological Control of Weeds* (E.S. Delfosse and R.R. Scott, Eds.). 2-7 February 1992, Canterbury, New Zealand; DSIR/CSIRO. 75-80pp.

Wilson, F. (1960). A review of the biological control of insects and weeds in Australia and Australian New Guinea. *Commonwealth Institute* of *Biological Control,* 1:102pp.

Winder, J.A., Harley, K.L.S. and Kassulke, R.C. (1984). *Uroplata lantanae* Buzzi and Winder (Coleoptera: Chrysomelidae: Hispinae), a potential biological control agent of *Lantana camara* in Australia. Bulletin of Entomological Research, 74:327-340.

Winder, J.A., Sands, D.P.A. and Kassulke, R.C. (1988). The life history, host specificity and potential of Alagoasa parana Samuelson (Coleoptera: Chrysomelidae) for biological control of *Lantana camara* in Australia. Bulletin of Entomological Research, 78: 511-518.

Witt, A. (2013). CABI, ICRAF Complex, United Nations Avenue, Gigiri, P.O. Box 633-00621, Nairobi, Kenya. Source: Winston, *et al.* (2014).

Wood, A.R. (2013). Agricultural Research Council- Plant Protection Research Institute, Weeds Research, P/Bag X5017, Stellenbosch 7600 South Africa

Wood, A.R. and M. Scholler. (2002). *Puccinia abrupta var. partheniicola* on *Parthenium hysterophorus* in southern Africa. Abstract. Plant Disease 86: 327.

Young, R.G. (1982). Recent work on biological control in Papua New Guinea and some suggestions for the future. Tropical Pest Management, 28: 107-114.

Zachariades, C., Hoffmann, J.H. and Roberts, A.P. (2011). Biological control of mesquite *(Prosopis species)* (Fabaceae) in South Africa. African Entomology, 19(2): 402-415.

Zimmerman, E.C. (1978). Insects of Hawaii. Vol. 9. University of Hawaii Press, Honolulu, Hawaii. 1903 pp.

Zimmermann, H. (2013). Helmuth Zimmermann & Associates, P.O. Box 974, Faerie Glen 0043, South Africa. Source: Winston, et al. (2014).

Zimmermann, H.G. (1991). Biological control of mesquite, *Prosopis* spp. (Fabaceae), in South Africa. Agriculture, Ecosystems and Environment, 37: 175-186.

7 BIOPROSPECTING OF INVASIVE ALIEN SPECIES

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INTRODUCTION

The invasive alien species are exotic organisms that occur outside their natural habitat which contributing to the loss of economic or environmental structure in worldwide, including in India (Marbuah *et al.*, 2014). For this concern, Convention for Biological Diversity (1992) visualize "biological invasion of alien species as the second worst threat after habitat destruction". Because, alien plants would spread quickly due to our mobile society as well as the intentional transportation of ornamental and forage plants (Downey and Richardson, 2016). Hence, it influences the biodiversity badly, as well as decline or elimination of native species through competition, predation, or transmission of pathogens and additionally the disruption of native systems and ecosystem functions. Thus, the damage is intensified by global climate change, pollution, habitat loss, and human-induced disturbance (Acevedo-Whitehouse and Duffus, 2009). In view of globalization of Indian economy and significant increase in international travel and trade, introduction, establishment, and spread of alien species is probably going to escalate in India with serious ecological and socioeconomic consequences.

Furthermore, an attempt to distinguish the risks exhibit by alien and invasive plant species, management actions are enforced to stop introductions, eradicate infestations before they become established and contain the spread of copious or resistant taxa. In several cases, the management strategies like cutting, mowing and extirpation are not fully effective, either for eradication or containment purposes, because invasive species rely on efficient spreading systems guaranteeing their long-term persistence (Fletcher *et al.*, 2015). Moreover, these methods demand immense economic resources, not only to help direct containment but also for the management of the biomass resulting from extirpation and cutting activities. Considering that global climate change is probably going to exacerbate the negative effects of invasive alien species because it can foster their additional spread particularly within the most fertile areas, the economic resources and human energy demanded managing invasive plants are expected to extend.

In addition, the engagement of the citizen and different stakeholders to boost actions aimed toward controlling the invaders creates societal challenges that policymakers are asked to prioritize. At the same time, characteristic innovative ways that to remodel invasive plants from 'problems to resources' also represent a crucial challenge for modern societies (Guzzetti *et al.*, 2017).

BIOPROSPECTING OF INVASIVE ALIEN PLANTS

Biodiversity prospecting or bioprospecting is the systematic search for biochemical and genetic information in nature in order to develop commercially-valuable products for pharmaceutical, agricultural, cosmetic and other applications. Bioprospecting potential of selected IAPS to find new compounds and antioxidant phytocomplexes to be used in different sectors of human interest (e.g. pharmaceutical, cosmetic, and nutrition) are discussed here.

Ageratum conyzoides (L.) L.

Ageratum conyzoides has been used in traditional system of medicine of various countries to treat different ailments. So far 160 compounds have been identified from this plant and the crude fractions have shown multifarious pharmacological activities which are found to be safe. In this context, this invasive plant is reported to have antiulcerogenic (Silva *et al.*, 1991), analgesic (Magalhaes *et al.,* 1997), anti-inflammatory (Margort *et al.*, 2000; Marques-Neto, 1988), anticataleptic (Abena *et al.*, 1996), antidiabetic (Pattnaik *et al.*, 1996), cytotoxic (Tyagi *et al.,* 1994), hepatoprotective (Fiori *et al.*, 2000), anticonvulsant (Miller, 1968), radioprotective (Ragasa *et al.*, 1998), antidotal (Garcia *et al.*, 1999), antioxidant (Kawaii *et al.*, 1999), anthelmintic (Gbolade *et al.*, 1999), allelopathic (Calle *et al.*, 1990), insecticidal (Raja *et al.*, 1987), wound healing (Fagoonee *et al.*, 1981), uterine and bronchodilating (Degheele *et al.*, 1986) potential.

Alternanthera philoxeroides (Mart.) Griseb

This plant has been reported to contain phaeophytin a, pheophytin a', oleanolic acid, -sitosterol, 3- -hydroxystigmast-5-en-7-one, -spinasterol, 24-methylenecycloartanol, cycloeucalenol, and phytol (Fang *et al.*, 2006). Traditionally the plant has been used for treatment of acute brain fever, measles and herpes zoster in China. Further, it would be suggested for an antipyretic agent and dressing for wounds and ulcers. Similarly, the aqueous extract of this plant has been shown to inhibit Human Immunodeficiency Virus (HIV) (Zhang *et al.*, 1988), and its petroleum ether extract has been found to be effective against dengue virus (Jiang et al., 2005). Chikusetsusaponin-IVa (CS-IVa) isolated from the plant showed antiviral activities against HSV-1, HSV-2, human herpes, measles virus, and mumps virus. On the other hand, CS-IVa has potent inhibitory activity on adipocyte differentiation in order that it is considered as a useful food material to treat obesity. The methanolic extract from the leaves are found to have antioxidant, antimicrobial and glucosidase inhibitory activities.

Chromolaena odorata (L.) R.M. King & H. Rob.

The isolated phenolic compounds such as Protocatechuic, *p*-coumaric, ferulic, *p*-hydroxybenzoic and vanillic acids from the *C. odorata* are protecting the cultured skin cells from oxidative damage (Phan *et al.*, 2001). The flavones, luteolin and acacetin, are isolated from the plant which can be effective against human lung and breast cancer cell lines (Suksamrarn *et al.*, 2004). In addition, chalcone is extracted from leaves that found to possess both cytotoxic and anticlonogenic actions against a variety of cancer cell lines (Kouamé *et al.*, 2013). Flavonoid compounds are also isolated which can have high efflux inhibitory action against methicillin-resistant *Staphylococcus aureus* (MRSA), suggesting they can be good efflux inhibitors for MRSA (Johari *et al.*, 2012). The dry stems and leaves are known to be very rich in essential oils that are well known for their efficiency in treating minor ailments (Moni and Subramoniam, 1960).

The extracts, ethyl acetate and butanol of *C. odorata* leaves exhibited antibacterial activity against opportunistic human pathogens (Irobi, 1992; Caceres *et al.*, 1995, Atindehou *et al.*, 2013) that can inhibit the intestinal tract infection. Due to the presence of phenolic compounds, aqueous (Owoyele *et al.*, 2005) and ethanolic (Owoyele *et al.*, 2006) extract of *C. odorata* showed anti-inflammatory activity on rats for its acute and chronic forms of inflammation. The aqueous and ethanolic extract indicates significant activities even at a minimum concentration of 25 mg/kg (69.6%, 63.9%). The ethanolic extract of *C. odorata* leaves (Owoyele *et al.*, 2006) applied for the analgesic activities at doses of 25–200 mg/kg using various assays. In the hot plate latency assay, doses of 25–200 mg/kg of the ethanolic extract were administered to rats after which they were placed on a hot plate at 55°C. At doses of 100 and 200 mg/kg, there were significant increases in the reaction time from 1.8070.37 to 4.070.55 min after 60 min of administration. Further, the ethanolic extract of *C. odorata* leaves (Nudo *et al.*, 2012) having potential to reverse drug-induced immunosuppression, a common consequence of long-term use of cyclophosphamide (Cy) therapy in cancer patients (Bin-Hafeez *et al.*, 2001). This drug is known to cause leucopenia as it is cytotoxic, not only to cancer cells but to leucocytes as well.

The methanol and ethanol extracts of *C. odorata* (Raman *et al.*, 2012; Vijayaraghavan *et al.*, 2013) yielded the most effective DPPH radical scavenging activity (94.29%) due to the high amounts of polyphenols which seem to be a rich source of natural antioxidants. The antifungal activity of leaf ethanolic extract was more effective than the stem extract at higher concentrations against *Aspergillus flavus, A. glaucus, Candida albicans, C. tropicalis and Trichophyton rubrum* (Naidoo *et al.*, 2011). The anthelminthic activity was carried out with the methanolic extract that showed most effective against earthworms (Panda, *et al.*, 2010). *C. odorata* has been reported to possess antipyretic, antispasmodic (Taiwo *et al.*, 2000) and anti-malarial (Ongkana, 2003) activities. The aqueous and ethanolic extracts are also having anticonvulsant activity (Amazu *et al.*, 2013) in rats at doses of 25-100 mg/kg with valproic acid at 200 mg/kg as the standard. This activity may be as a result of the presence of alkaloids, flavonoids and kauronic acid that have been discovered in this species.

Eichhornia crassipes (Mart.) Solms

Alkaloids, phenols, terpenoids (Shanab *et al.*, 2010; Chantiratikul *et al.*, 2009), flavonoids, amino acids, phosphorous, protein, cyanide (Nyananyo *et al.*, 2007) and phenylphenalene-related compounds (DellaGreca *et al.*, 2009) are found from the *E. crassipes.* Further, it has relatively high ash content, about 25.7 % of the dry matter (Gunnarsson and Petersen 2007). In order to reduce the hazards posed by this weed, many applications have been envisioned. Currently, it is reckoned to be a resource of immense potential. Implication of the huge biomass has ramified into waste water treatment from dairies, tanneries, sugar factories, pulp and paper industries, palm oil mills, distilleries etc. (Jafari, 2010). During the removal of dye from raw sewage, pungent odour gradually vanished and deep yellowish colour turned into colourless in the final effluent sample. The nutrient-rich sludge can be used as bio-fertilizer and purified water seems suitable for irrigation of crops (Litter *et al.*, 2011).

Duck-weed, water fern and water lettuce are used for the removal of heavy metals from waste water (Mishra and Tripathi 2009). Similar to that, *E. crassipes* is also having heavy metal accumulation potential. This weed showed high tolerance and affinity towards heavy metals. This is because of the high cellulose content and its functional teams viz. carboxyl (–COO-), hydroxyl (–OH-), amino (–NH_2), sulfhydryl (–SH) which are responsible for the adsorption capacity to clean up numerous contaminated waters (Xia and Ma 2006). Ion exchange and electrostatic interaction with binding sites are principal mechanisms for the metal adsorption of *E. crassipes.* Due to high bioconcentration factor, the biosorption of Fe, Pb (II), Cd (II), Zn (II), Cr (VI) ions will be successfully done with fast removal of metals in the initial stage of remediation. Furthermore, the dead biomass retained the metal adsorption capacity up to two cycles, indicating its prospects for the wastewater treatment and metal recovery (Junior *et al.*, 2008; Tan *et al.*, 2008; Jayaweera *et al.*, 2008; Mishra and Tripathi, 2009; Mahamadi and Nharingo, 2010; Saraswat and Rai, 2010).

Contaminants in municipal wastewater like 92 % of nitrate, 67 % of phosphorus, 81 % of ammonia and 49 % of COD can be effectively removed by this weed (Kutty *et al.*, 2009). Furthermore, *E. crassipes* is used to remove cyanides from gold mines effluents (Ebel *et al.*, 2007) and potential candidate for phytoremediation of radionuclides (Saleh, 2011). It can be used as a tertiary treatment agent for kraft mill pulp effluents from aquatic systems (Lagos *et al.*, 2009) and potential candidate for ethanol production by simultaneous saccharification and fermentation of the biomass (Mishima *et al.*, 2008). Due to high cellulose content, *E. crassipes* can be used in paper industry (Ndimele *et al.*, 2011). While hydrolyze the cellulose content that produces many industrially important chemicals. For example, Levulinic acid is obtained from the acid hydrolysis which can be used for various organic compound synthesis viz. flavours, biodiesel blends, polymers and pharmaceuticals (Ndimele *et al.*, 2011). Always, there is a need for cheap and nutrient rich feed (Aboud *et al.*, 2005). Leaves and shoots of the weed showed more digestibility than the whole plant. Thus, it can be recommended for the goat feed (Dada, 2002). The decomposed *E. crassipes* supports for the enhancement of nutritional status in soil (Chukwuka and Omotayo, 2008) and used for mineral-rich mushroom cultivation (Gupta *et al.*, 2007). It is suggested that *E. crassipes* could be a potential algaecide to control harmful algal blooms due to the presence of alkaloids in weed (Shanab *et al.*, 2010).

Lantana camara L

Lantana camara L has been considered as a major medicinal plant for the treatment a large type of disorders (Ross, 1999; Saxena, *et. al,* 2012; Priyanka *et al.,* 2013). Secondary metabolites like flavones, isoflavones, flavonoids, anthocyanins, coumarins, lignans, catechins, isocatechins, alkaloids, tannin, saponins and triterpenoids are isolated from this plant species (Saxena *et al.,* 2012). For instance, leaf extracts from *L. camara* exhibit anti proliferative, antimicrobial, fungicidal, insecticidal and nematicidal potential (Priyanka *et al.*, 2013). Furthermore, the shoot extracts of this plant have strong antioxidant activities (APFISN, 2015). In Central and South America, the leaves are made into a poultice to treat sores, chicken pox, and measles and are further used to treat fever, cold, rheumatism, respiratory disorder, and high pressure. The powdered root in milk is given to kids for stomach-ache (Saxena *et al.*, 2012; Priyanka *et al.*, 2013) in Ghana. However, in India, the leaves of the plant are boiled for tea and the decoction is given as a remedy against cough and used as lotion to heal wounds. The pounded leaves are applied to cuts, ulcers and swellings (Saxena *et al.*, 2012). *Lantana camara* has several therapeutic uses, mainly as herbal medicine. The twigs and stems are useful fuel for cooking and heating in several regions of India (Sharma *et al.,* 1988), although it is less significant than alternative fuel sources like windrows, woodlots or natural bush (Varshney *et al.*, 2006). It has been suggested for the use of fuel ethanol production in varied research findings (Sharma *et al.*, 1988; Inada *et al.*, 1997; Varshney *et al.*, 2006). For the replacement of traditional forest based species like wood and bamboo, *Lantana camara* contained 75.03% hollo-cellulose, 8.461% extractive, 18.21% lignin, and 2.31% silica that can be used for the potential source of raw material in paper production (Ray *et al.*, 2006; Naithani and Pande, 2009; Bhatt *et al.,* 2011).

Parthenium hysterophorus L.

The decoction of *P. hysterophorus* has been utilized in ancient drugs to treat fever, diarrhoea, neurologic disorders, urinary tract infections, dysentery, malaria and as emmenagogue (Surib-Fakim *et al.,* 1996). It has been found to be pharmacologically active as analgesic in muscular rheumatism, therapeutic for neuralgia and as vermifuge (Maishi *et al.,* 1998). This weed is additionally reported as promising remedy against hepatic amoebiasis. Parthenin, the main constituent of the plant, exhibits important medicinal attributes as well as antitumor property (Venkataiah *et al.*, 2003). The methanol extract of the flowers showed significant antitumor activity and parthenin exhibited cytotoxic properties against T cell leukemia, HL-60, and HeLa cancer cell lines (Das *et al.*, 2007). The extract of *P. hysterophorus* is tested for its in vitro and in vivo antitumor potential that provides positive results in terms of tumour size reduction and overall survival of cell lines (Ramos *et al.*, 2002). The aqueous extract has hypoglycaemic activity against alloxan-induced diabetic rats (Patel *et al.,* 2008). Furthermore, the flower extract of this weed will be used for developing drug for diabetes mellitus. The aqueous extract (Parashar *et al.*, 2009) is reducing the silver ions present in the silver nitrate complex for the synthesis of silver nanoparticles. This discovery can promote this noxious weed into a valuable plant for nanotechnology-based industries in the future. Applications of such eco-friendly nanoparticles in bactericidal, wound healing and other medical and electronic applications make this method potentially exciting for the large-scale synthesis of other nanomaterials.

Prosopis juliflora (Sn.) Dc.

Traditionally, *Prosopis juliflora* is employed in human food and as a source of wood in endemic regions (Fagg and Stewart, 1994; Guilherme *et al.,* 2009), the fruits (pods) are often used to produce variety of food products like flour, syrups and alcoholic and non-alcoholic drinks (Gorgatti Netto 1987; Lima and Lima, 1985; Negreiros 1988; Vieira *et al.,* 1995; Guilherme *et al.,* 2009). The pods of the species are extensively used as feed for cattle (Silva, 1981). Moreover, various parts, bark, leaves, pods and flower would be used for the treatment of respiratory disease (Kayani *et al.,* 2014), dermatologic conditions and canal disorders (Gispert and Rodriguez, 1998) in traditional practices.

In addition to that, several studies demonstrate the technological and biotechnological potentials of *P. juliflora* in various areas such as production of activated carbon (Kumar and Tamilarasan, 2013), tannery effluent treatment

(Sharmila *et al.,* 2013) and as a bioindicator of metal accumulation (Beramendi-Orosco *et al.*,2013). Due the similarity of *Prosopis juliflora* gum to other gums used in the pharmaceutical and cosmetic industry, the species shows the potential of use in these areas as an emulsifying (Goycoolea *et al.,*1997) and encapsulating agent (Beristain and Vernon-Carter 1994).

Breads are made from the flour which can be obtained by grinding ripe and dry pods. Furthermore, an aqueous extract is yielded a honey-like syrup that has a high content of proteins and carbohydrates, a refreshing drink can be made by maceration and a powder that can be used as a coffee substitute are the main uses for human consumption (Gorgatti Netto 1987; Negreiros 1988; Machado and Figueiredo, 2000). On the other hand, *Prosopis juliflora* would be used for animal feeding in other animal diets such as layer quails (Silva *et al.*, 2002), Nile tilapia (Carvalho *et al.,* 2012), horses (Medeiros *et al.*, 2012), sheep and goats (Riet-Correa *et al.,* 2012). Furthermore, *Prosopis juliflora* wood is a good quality wood for carpentry and joinery, and can be used for making rustic furniture, sleepers, poles, stakes, (Braga 1976; Karlin and Ayerza 1982; Mendes and Alves 1988; Gomes 1999), firewood and charcoal (Barbosa, 1986). The antimicrobial activity of *P. juliflora* crude extracts evaluating the antimicrobial potential use to combat microorganisms in crop plants (Satish *et al.,* 1999), ruminants to decrease gas production during digestion (Dos Santos *et al.,* 2013), effluent treatment (Raja *et al.,* 2012) and human bacteria and fungi (Lima and Lima, 1985; Ahmad *et al.,*. 1986, 1989; Ca´ceres *et al.,* 1995; Satish *et al.,* 1999; Singh and Swapnil 2011; Raja *et al.,* 2012; Dos Santos *et al.,* 2013).

P. juliflora leaf extracts (Ca´ceres *et al.,* 1995) was used for the treatment of gonorrhea and synthesis of silver nanoparticles (Raja *et al.,* 2012) which showed a potential use in the effluent treatment process for reducing the microbial load in industrial and medical application. The antioxidant potential of aqueous extract demonstrated a protective role against hepatotoxicity induced by *S. aureus* by elevating intrinsic antioxidant mechanism (Prasad *et al.,* 2011; Almaraz-Abarca *et al.*, 2007). Furthermore, the ethanolic extracts from fruit and flower could be considered to possess antiplasmodial activity (Simonsen *et al.,* 2001). The screening of crude plant extracts showed a potential use as a larval control agent against *Aedes albopictus,* a vector of dengue and chikungunya (Yadav *et al.,* 2014; Yadav *et al.,* 2015). Furthermore, the aqueous extract showed insecticidal and repellent activity against whitefly and *T. castaneum* (Cavalcante *et al.,* 2006; Pugazhvendan *et al.,* 2012). Cholinesterase inhibitors have been a promising drugs used for Alzheimer's disease. Juliflorine is an alkaloid isolated from *P. juliflora,* which showed in vitro inhibitory activity against acetylcholinesterase (AChE) and butyryl-cholinesterase (BChE) (Choudhary *et al.,* 2005).

The leaf and root bark ethanol extract could be used in the treatment and prevention of helminthic infections. This is due its chemical composition based on saponins, tannins and alkaloids (Odhiambo *et al.,* 2014). Anti-emetic activity of leaves methanol extracts on male chicks that showed 73.64 % antiemetic activity by reducing the retching, compared to chlorpromazine (Hasan *et al.,* 2012). *Prosopis juliflora* is used for intoxication of animals that has been historically reported in the USA (Dollahite 1957, 1964), Peru (Baca *et al.,* 1967) and Brazil (Figueiredo *et al.,* 1995; Lima *et al.*, 2004; Silva *et al.,* 2006; Tabosa et al., 2006), mainly in cattle and goats. *P. juliflora* is used as a binder and its mucilage is exists in diclofenac sodium tablets (Selvi *et al.,* 2010; Prajapati *et al.,* 2013). Furthermore, it is used for synthesis of a chemically modified galactomannan as well as the synthesis of a hydrogel (Reis *et al.,* 2003).

CONCLUSION

The increased threat by invasive alien plant species contribute to reduction of agriculture, livestock and forest productivity, altering soil quality and promoting land degradation and affecting essential ecosystem functions by altering species composition, fire regimes, food web, nutrient cycling and hydrology. Thus, various management procedures have been adapted to control the invasive plants species, but no effective strategy has been developed till date. On the other hand, the highly troublesome invasive alien plant are being used as traditional medicines and the isolated compounds from the plant species are having wide range pharmacological potential as evidenced from the literature survey. In this manner, bioprospecting of these invasive plants could be an alternate tool for its management.

REFERENCES

Abena, A.A., Ouamba, J.M. and Keita, A. (1996). Anti-inflammatory, analgesic and antipyretic activities of essential oil of *Ageratum conyzoides.* Phytotherapy Research, 10:S164-5.

Aboud, A.A.O., Kidunda, R.S. and Osarya, J. (2005). Potential of water hyacinth *(Eicchornia crassipes)* in ruminant nutrition in Tanzania. Livestock Research for *Rural Development,* 17:8.

Acevedo-Whitehouse, K. and Duffus, A.L.J. (2009). Effects of environmental change on wildlife health. Philosophical transactions of the Royal Society of London. Series B, Biological sciences, 364(1534):3429-3438.

Ahmad, A., Ali Khan, K., Ahmad, V.U. and Qazi, S. (1986).Antibacterial activity of juliflorine isolated from *Prosopis juliflora,* Planta Med, 285-8.

Ahmad, A., Khursheedm, A.K., Sabiha, Q. and Viqaruddin, A. (1989).Antifungal activity of some hydrosoluble *Prosopis juliflora* alkaloids, Fitoterapia, 60:86-9.

Almaraz-Abarca, N., da Graca Campos M., Avila-Reyes, J. *et al.* (2007). Antioxidant activity of polyphenolic extract of monofloral honeybee -collected pollen from mesquite *(Prosopis juliflora,* Leguminosae). Journal of Food Composition and Analysis, 20:119-124.

Amazu, L.U., Omoregie, P., Ajugwo, A.O., Ifezulike, C.C. and Azikiwe, C.C.A., (2013). Anticonvulsant potency of the leaf extract of *Chromolaena odorata* in rats. Unique Res. J Med. Sci, 1:64–69.

Baca, S.F., Vallenas, A. and Novoa, C. (1967). Estudio experimental de la ‘‘Coquera’’’ en caprinos. Revta Fac Med Vet, 18:28.

Barbosa, J.A. (1986). Avaliac¸a˜o qualitativa e quantitativa do carva˜o e dos condensados produzidos na carbonizac¸a˜o da madeira de algaroba *(Prosopis juliflora* DC). Dissertation, *Vicosa Federal University*

Beramendi-Orosco L. E., Rodriguez-Estrada M. L., Morton-Bermea O., Romero F. M., Gonzalez-Hernandez G. and Hernandez-Alvarez E. (2013). Correlations between metals in tree-rings of *Prosopis julifora* as indicators of sources of heavy metal contamination. Applied Geochemistry. 39:78–84.

Bhatt, N., Gupta, P.K. and Naithani, S. (2011). Ceric-induced grafting of Acrylonitrile onto Alpha Cellulose isolated from *Lantana camara.* Cellulose Chemistry and Technology, 45 (5-6): 321-327.

Bin-Hafeez, B., Ahmad, I., Haque, R. and Raisuddin, S., (2001). Protective effect of *Cassia occidentalis* L. on cyclophosphamide-induced suppression of humoral immunity in mice. Journal of Ethnopharmacology, 75:13-18.

Braga, R. (1976). Plantas do Nordeste: Especialmente do Ceara´. ESAM, Natal

Caceres, A., Menendez, H., Mendez, E., Cohobon, E., Samayoa, B.E., Jauregui, E., Peralta, E. and Carrillo, G. (1995). Anti-gonorrhoeal activity of plants used in Guatemala for the treatment of sexually transmitted diseases. Journal of Ethnopharmacology, 48:85-88.

Calle, J., Rivera, A., Luis, J.G., Aguiar, Z., Nimeyer, H.M. and Nathan, P.J. (1990). Insecticidal activity of the petroleum ether extract of *Ageratum conyzoides* L. Revista Colombiana de Química, 19:91-6.

Carvalho, J.S.O., Azevedo, R.V.D, Ramos, A.P.D.S. *et al.,* (2012). Agro industrial byproducts in diets for Nile tilapia juveniles. *Revista* Brasileira de Zootecnia, 41:479-484.

Cavalcante, G.M., Moreira, A.F.C. and Vasconcelos, S.D. (2006). Poten-cialidade inseticida de extratos aquosos de esseˆncias flo-restais sobre mosca-branca. Pesquisa Agropecuária Brasileira, 41:9–14

Chantiratikul, P., Meechai, P. and Nakbanpotecc, W. (2009). Antioxidant activities and phenolic contents of extracts from *Salvinia molesta* and *Eichornia crassipes.* Research Journal of Biological Sciences, 4:1113-1117.

Choudhary, M.I., Nawaz, S.A., Zaheer-ul-Haq, Azim, M.K., Ghayur, M.N., Lodhi, M.A., Jalil, S., Khalid, A., Ahmed, A., Rode, B.M., Atta-ur-Rahman, Gilani, A.U. and Ahmad, V.U. (2005). Juliflorine: a potent natural peripheral anionic-site-binding inhibitor of acetylcholinesterase with calcium-channel blocking potential, a leading candidate for Alzheimer's disease therapy, Biochem Biophys Res Commun, 15, 332 (4):1171-7.

Chukwuka, K.S. and Omotayo, O.E. (2008). Effects of Tithonia green manure and water hyacinth compost application to nutrient depleted soil in South-Western Nigeria. International Journal of Soil Science, 3:69-74.

Dada, S.A. (2002). The utilization of water hyacinth *(Eichhornia crassipes)* by West African dwarf (wad) growing goats. African Journal of Biomedical Research, 4:147–149.

Das, B., Reddy, V.S., Krishnaiah, M., Sharma, A.V.S., Ravi Kumar, K., Rao, J.V. and Sridhar, V. (2007). Acetylated pseudoguaianolides from *Parthenium hysterophorus* and their cytotoxic activity. Phytochemistry, 68:2029-2034.

Degheele D, Fontier H, Auda M, DeLoof A. Rijksuniv Gent (1986); 51:101.

DellaGreca, M., Previtera, L. and Zarrelli, A. (2009). Structures of new phenylphenalene-related compounds from *Eichhornia crassipes* (water hyacinth). Tetrahedron, 65:8206-8208.

Dollahite, J.W. (1957). Malnutrition in cattle on an unbalanced diet of mesquite beans. *Texas Agricultural* Experiment *Station,* 11:4.

Dollahite, J.W. (1964). Management of the disease produced in cattle on an unbalanced diet of mesquite beans. Southwest Vet, 17:132

Dos Santos, E.T., Pereira, M.L., da Silva, C.F., Souza-Neta, L.C., Geris R, Martins, D., Santana, A.E., Barbosa, L.C., Silva, H.G., Freitas, G.C., Figueiredo, M.P., de Oliveira, F.F. and Batista, R. (2013). Antibacterial activity of the alkaloid-enriched extract from *Prosopis juliflora* pods and its influence on in vitro ruminal digestion, Int J Mol Sci, 14(4):8496-516.

Downey, P.O. and Richardson, D.M., (2016). Alien plant invasions and native plant extinctions: a six-threshold framework. AoB PLANTS 8, plw047.

Ebel, M., Evangelou, M.W.H. and Schaeffer, A. (2007). Cyanide phytoremediation by water hyacinths *(Eichhornia crassipes)*. Chemosphere, 66:816-823.

Fagg, C.W. and Stewart, J.L. (1994). The value of Acacia and Prosopis in arid and semiarid environments. Journal of Arid Environments, 27:23.

Fagoonee, I. and Umrit, G. (1981). Antigonadotropic Hormones from the Goatweed, *Ageratum conyzoides. Insect Science and Its Application*, 4:373-6.

Fang, J.B., Duan, H.Q., Zhang, Y.W. and Yoshihisa, T. (2006). Chemical constituents from herb of *Alternanthera philoxeroides.* Zhongguo Zhong Yao Za Zhi, 31:1072-1075.

Figueiredo, L.J.C., Ferreira, M.M., Ta´vora, J.P.E. *et al.,* (1995). Estudo cli´nico e ana´tomopatolo´gico da doenc¸a ‘‘cara torta’’em bovinos no nordeste brasileiro. Arq Med Vet 18:9

Fiori ,A C .Schwan Estrada ,K R .Stangarlin ,J R .Vida ,J B .Scapim ,C A and Cruz ,M E . (2000) Antifungal activity of leaf extracts and essential oils of some medicinal plants against *Didymella bryoniae.* Journal of Phytopathology , 148 483 7 .

Fletcher ,C S .Westcott ,D A .Murphy ,H T .Grice ,A C .and Clarkson ,J R . 2015 () Managing breaches of containment and eradication of invasive plant populations .The Journal of applied ecology ,52 (1) 59 68 .

Garcia ,MD . Saenz ,MT . Gomez ,MA .and Fernandez ,MA . (1999) Topical anti inflammatory activity of phytosterols isolated from *Erygium foetidum* on chronic and acute inflammation models Phytotherapy Research ,13 78 80 .

Gbolade ,AA . Onayade ,OA .and Ayinde ,BA . (1999) Insecticidal activity of Ageratum conyzoides L .volatile oil against *Callosobruchus chinensis* F in seed treatment and fumigation laboratory tests :Insect Science and its application . Insect Science and its Application ,19 237 .

Gispert , M . Rodriguez , H . (1998) LosCoras : Plantas Alimenticiasy MedicinalesdesuAmbiente Natural . Mexico CONACULTA p 128 .

Gomes ,J J . (1999) Technological characteristics of algarobeira (*Prosopis juliflora* DC) Contribution to its rational use . Campina Grande UFPB ,118p Master Thesis

Gorgatti ,Netto ,A . (1987) Considerac ¸o˜es sobre a algaroba (*Prosopis juliflora* (Sw) D.C.). Ciência e Tecnologia de Alimentos, 17:1–27.

Goycoolea, F.M., Calderón de la Barca A.M., Balderrama, J.R. and Valenzuela, J.R. (1997). Immunological and functional properties of the exudate gum from Northwestern Mexican Mesquite (*Prosopis* spp.) in comparison with gum arabic, Int J Biol Macromol, 21:29-36.

Guilherme, AA., Honorato, TL. and Dornelles, AS. et al., (2009). Quality evaluation of mesquite (*Prosopis juliflora*) pods and cashew *(Anacardium occidentale)* apple syrups. Journal of Food Process Engineering, 32:606-622.

Gunnarsson, CC. and Petersen, CM. (2007). Water hyacinths as a resource in agriculture and energy production: a literature review. Waste Management, 27:117-129.

Gupta, R., Mutiyar, P.K., Rawat, N.K., Saini, M.S. and Garg, V.K. (2007). Development of a water hyacinth-based vermireactor using an epigeic earthworm *Eisenia foetida.* Bioresource Technology, 98:2605-2610.

Guzzetti, L., Galimberti, A., Bruni, I., Magoni, C., Ferri, M., Tassoni, A., Sangiovanni, E., Dell'Agli, M. and Labra, M. (2017). Bioprospecting on invasive plant species to prevent seed dispersal. Scientific reports, 7(1):13799-13799.

Hasan, MMU., Azhar, I., Muzammil, S. *et al.,* (2012). Anti-emetic activity of some leguminous plants. *Pakistan* Journal of *Botany,* 44:389-391.

Inada, A., Nakanishi, T., Tokuda, H. and Sharma, O.P. (1997). Antitumor activities of lantadenes on mouse skin tumors and mouse hepatic tumors. Plantations Medicine, 63: 476-478.

Irobi, O.N., (1992). Activities of *Chromoleana odorata* (Compositae) leaf extract against *Pseudomonas aeruginisa* and *Streptococcus faecalis.* Journal of Ethnopharmacology, 37:81–83.

Jafari, N. (2010). Ecological and socio-economic utilization of water hyacinth (*Eichhornia crassipe*s Mart Solms). *Journal of Applied Sciences and Environmental Management, 1*4:43-49.

Jayaweera, MW., Kasturiarachchi, JC., Kularatne, RKJA., Wij-eyekoon, SLJ. (2008). Contribution of water hyacinth *(Eichhornia crassipes* (Mart.) Solms) grown under different nutrient conditions to Fe-removal mechanisms in constructed wetlands. Journal of Environmental Economics and Management, 87:450-460.

Jiang, WL., Luo XL. and Kuang SJ. (2005). Effect of *Alternanthera philoxeroides* Griseb against dengue virus in vitro. Di Yi Junyi Daxuw Xuebao, 25: 454-456.

Johari, S.A., Kiong, L.,S., Mohtar, M., Isa, M.,M., Man, S., Mustafa, S. and Ali, A.,M., (2012). Efflux inhibitory activity of flavonoids from *Chromolaena odorata* against selected methicillin-resistant *Staphylococcus aureus* (MRSA) isolates. African journal of microbiology research, 6:5631-5635.

Junior, ACG., Lindino, CA., Da Rosa, MF., Bariccatti, R., Gomes, GD. (2008). Removal of toxic heavy metals cadmium, lead and chromium from swine biofertilizer, using an aquatic mac-rophyte *(Eichornia crassipes)* as a bioindicator. Acta Sci-entiarum Technol, 30:9–14.

Karlin, U.O. and Ayerza, H.R. (1982). O programa da algaroba naRepu´blica Argentina. Paper presented at the S*impo´sio Brasileiro sobre a Algaroba, Natal.*

Kawaii S, Tomono Y, Katase E, Ogawa K and Yano M. J.(1999) *Agric Food Chem;*47:128-35.

Kayani, S., Ahmad, M., Zafar, M., Sultana, S., Khan, M. Pukhtoon Zada, Ashraf, M. Aqeel, Hussain, J., and Yaseen, G. (2014). Ethnobotanical uses of medicinal plants for respiratory disorders among the inhabitants of Gallies – Abbottabad, Northern Pakistan. Journal of ethnopharmacology, 156: 47-60.

Kouamé, P.B., Jacques, C., Bedi, G., Silvestre, V., Loquet, D., Barillé Nion, S., Robins, R. J. and Illa Tea, I., (2013). Phytochemicals isolated from leaves of *Chromolaena odorata*: impact on viability and clonogenicity of cancer cell lines. Phytotherapy Research, 27, 835-840.

Kutty, SRM., Ngatenah, S.N.I., Isa, M.H. and Malakahmad, A. (2009). Nutrients removal from municipal wastewater treatment plant effluent using *Eichhornia crassipes*. World Academy of Science, Engineering and Technology, 60:826–831.

Lagos, C., Urrutia, R., Decap, J., Mart ?nez ,M and Vidal ,G . (2009) *Eichhornia crassipes* used as tertiary color removal treatment for Kraft mill effluent Desalination ,246 45 54 .

Lima ,C A A and Lima ,E D A . (1985) Estudo da utilizac ̧a˜o da farinha integral da algaroba (*Prosopis juliflora* SW) D.C.) naa alimentac ̧a˜o humana. Agropecu Te´c 6:10

Litter, M.I., Alarco´n-Herrera, M.T, Arenas, M.J., Armienta, M.A., Avile´s M, Ca´ceres, R.E., Cipriani, H.N., Cornejo, L., Dias, L.E., Cirelli, A.F., Farfa´n E.M., Garrido, S., Lorenzo, L., Morgada, M.E., Olmos-Ma´rquez, M.A. and Pe´rez-Carrera, A. (2011). Small-scale and household methods to remove arsenic from water for drinking purposes in Latin America. Sci Total Environ,

Machado, R.L.P. and Figueiredo, A.A. (2000). Formulac ̧a˜o, composic ̧a˜o e caracter ?'sticas da bebida preparada com extrato aquoso (polpa) das vagens de algarobeira (*Prosopis juliflora*) Paper presented at XVI Congresso Brasileiro de C &T de Alimentos ,Fortaleza .

Magalhaes ,J F . Viana ,C F . Aragao ,AG .Jr ,Moraes ,VG . Ribeiro ,RA .and Vale ,MR . (1997) Analgesic and anti - inflammatory activities of Ageratum conyzoides in rats Phytotherapy Research ,11 183 .

Mahamadi, C. and Nharingo, T. (2010). Competitive adsorption of Pb 2, Cd 2 and Zn 2 ions onto Eichhornia crassipes in binary and ternary systems. Bioresource Technology, 101 859-864.

Maishi, A.I., Ali, P.K.S., Chaghtai, S.A. and Khan, G. (1998). A proving of Parthenium hysterophorus, L. British Homoeopathic Journal, 87 17-21.

Marbuah, G., Gren, I.M. and McKie, B. (2014). Economics of Harmful Invasive Species: A Review. Diversity, 6 500-523.

Margort deSilva, M.J., Capaz, F.R. and Vale, M.R. (2000). Effects of water soluble fraction from leaves of Ageratum conyzoides on smooth muscle. Phytotherapy Research, 14 130.

Marques Neto, J.F., Lapa, A. and Kubota, M. (1988). Efeitos do Ageratum conyzoides Linee no tratamento da artrose. Revista Brasileira de Reumatologia, 28 34-7.

Medeiros, M.A., Riet Correa, F. and Pessoa, AFA, et al. (2012). Utilizac?a˜o de vagens de *Prosopis juliflora* na alimentac¸a˜o de bovinos e equinos. Pesquisa Veterinária Brasileira, 32:1014-1016.

Mendes, B.V. (1989). Potencialidades de Utilizac¸a˜o da Algar-obeira (*Prosopis juliflora* (SW) DC) no Semi-a´rido Brasileiro. Colec¸a˜o Mossoroense, Mossoro´

Miller JA, and Wood HC. 1968 US Patent;121:307.

Mishima, D., Kuniki, M., Sei, K., Soda, S., Ike, M. and Fujita, M. (2008). Ethanol production from candidate energy crops: water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes* L.). Bioresource Technology, 99:2495–2500.

Mishra, V.K. and Tripathi, B.D. (2009). Accumulation of chromium and zinc from aqueous solutions using water hyacinth *(Eichhornia crassipes)*. Journal of Hazardous Materials, 164:1059-1063.

Moni, N.S. and Subramoniam, R., (1960). Essential oil from *Eupatorium odoratum* – a common weed in Kerala. Indian Forester. 86, 209.

Muthaiyan, Kumar and Tamilarasan, R. (2013). Modeling of experimental data for the adsorption of methyl orange from aqueous solution using a low cost activated carbon prepared from *Prosopis juliflora*. Polish Journal of Chemical Technology. 15.

Naidoo, K.K., Coopoosamy, R.M. and Naidoo, G., (2011). Screening of *Chromolaena odorata* (L.) King and Robinson for anti-bacterial and anti-fungal properties. Journal of Medicinal Plants Research, 5:4859-4862.

Naithani, S., Pande and P.K. (2009). Evaluation of *Lantana camara* Linn. stem for pulp and paper making. Indian Forester, 135 (8): 1081-1087.

Ndimele, P.E., Kumolu-Johnson, C.A. and Anetekhai, M.A. (2011). The invasive aquatic macrophyte, water hyacinth {*Eichhornia crassipes* (Mart.) Solm-Laubach: Pontedericeae}: problems and prospects. Research Journal of Environmental Sciences, 5:509–520.

Negreiros, A.N.M. (1988). *Prosopis juliflora* pod flour and Syrup processing and nutritional evaluation. FAO Publishers, Recife.

Nudo, L.P., Elena, S. and Catap, P.H.D.(2012). Anti-immunosuppressive effect of *Chromolaena odorata* (L.) King & Robinson (Asteraceae) leaf extract in cyclophosphamide-injected balb/C mice. Philipp. J. Sci,141: 35-43.

Nyananyo, B.L., Gijo, A. and Ogamba, E.N. (2007). The physico-chemistry and distribution of water hyacinth (*Eichhornia crassipes)* on the river Nun in the Niger Delta. Journal of Applied Sciences and Environmental Management, 11:133-137.

Odhiambo, R.S., Patrick, K.G., Helen, K.L. et al., (2014). Evaluation of in vitro ovicidal activity of ethanolic extracts of *Prosopis juliflora* (Sw.) DC (Fabaceae). IOSR Journal of Pharmacy and Biological Sciences, 9:15–18

Ongkana, R., (2003). Phytochemistry and anti-malarial activity of *Eupatorium odoratum*. (L.). Thesis submitted to Mahidol University, Bangkok, Thailand.

Owoyele, V.B., Adediji, J.O. and Soladoye, A.O., (2005). Anti-inflammatory activity of aqueous leaf extract of *Chromolaena odorata.* Inflammo pharmacology 13, 479–484.

Owoyele, V.B., Soladoye, A.O., Panda, D., Dash, K.S. and Dash, K.G. (2006). Anti-inflammatory and analgesic activities of ethanolic extract of *Chromolaena odorata* leaves. Chron. Common Dis.18, 397-406.

Panda, D., Dash, K.S. and Dash, K.G., (2010). Qualitative phytochemical analysis and investigation of anthelmintic and wound healing potentials of various extracts of *Chromolaena odorata* LINN. Collected from the locality of Mohuda Village, Berhampur (South Orissa). International Journal of Pharmaceutical Sciences Review and Research, 1:122-126.

Parashar, V., Parashar, R., Sharma, B. and Pandey, A. (2009). Parthenium leaf extract mediated synthesis of silver nano particles: a novel approach towards weed utilization. Digest Journal of Nanomaterials and Biostructures, 4:45–50.

Patel, V.S., Chitra, V.P., Prasanna, L. and Krishnaraju, V. (2008). Hypoglycemic effect of aqueous extract of *Parthenium hysterophorus* L. in normal and alloxan induced diabetic rats. Indian Journal of Pharmacology, 40:183–185.

Pattnaik, S., Subramanyam, V. R. and Kole, V. R. (1996). Antibacterial and antifungal activity of ten essential oils in vitro. Microbioscience. 86: 237.

Phan, T.T., Wang, P., See, R.J., Grayer, S.Y. and Chan, S.T., (2001). Phenolic compounds of *Chromolaena odorata* protect cultured skin cells from oxidative damage: implication for cutaneous wound healing. Biological and Pharmaceutical Bulletin, 24:1373-1379.

Prajapati, V.D., Jani, G.K. and Moradiya, N.G. et al., (2013). Pharmaceutical applications of various natural gums, mucilages and their modified forms. carbohydrate polymers, 92:1685–1699.

Prasad Hari, O., Navya, A., Vasu, D. et al., (2011). Protective effects of *Prosopis juliflora* against *Staphylococcus aureus.* International Journal of Pharmaceutical and Biomedical Research, 2:172-178.

Priyanka, N., Shiju, M.V., and Joshi, P.K. (2013). A framework for management of *Lantana camara* in India. In: Proceeding: International Academy of Ecology and Environmental Sciences, 3(4):306–323.

Pugazhvendan, S.R., Ross, P.R. and Elumalai, K. (2012). Insecticidal and repellant activities of four indigenous medicinal plants against stored grain pest, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). Asian Pacific Journal of Tropical Disease, 2(1):S16–S20.

Ragasa, C.Y., Tepora, M. and Rideout, J.A. (1998). ACGC Chemical Research Communications, 7:48.

Raja, K., Saravanakumar, A. and Vijayakumar, R. (2012). Efficient synthesis of silver nanoparticles from *Prosopis juliflora* *l*eaf extract and its antimicrobial activity using sewage. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 97:490–494.

Raja, S.S., Singh, A., Rao, S.J. (1987). Animal morphology and physiology, 34:35.

Raman, V.B., Samuel, L.A., Saradhi, P.M., Rao, N.B., Vamsi Krishna, N.A., Sudhakar, M., and Radhakrishnan, T.M., (2012). Anti-bacterial, antioxidant activity and GC–MS analysis of *Eupatorium odoratum*. Asian Journal of Pharmaceutical and clinical research, 5:99-106.

Ramos, A., Rivero, R., Victoria, M.C., Visozo, A., Piloto, J. and Garcìa, A. (2001) Assessment of mutagenicity in *Parthenium hysterophorus* L. Journal of Ethnopharmacology, 77:25 30.

Ray, A.K. and Puri, M.K. (2006) Modeling H Factor Kappa Number for Kraft Pulping of *Lantana camara* Plant - An Experimental Investigation. Advances in Bio Catalytics and Protein Engineering, 15:1 62.

Reis, A.V., Cavalcanti, O.A. and Rubira, A.F. et al. (2003) Synthesis and characterization of hydrogels formed from a glycidyl methacrylate derivative of galactomannan. International Journal of Pharmaceutics, 267:13 25.

Riet-Correa, F., Andrade, FRMD. and Carvalho, F.K.L. et al. (2012) Utilizacàão de vagens de *Prosopis juliflora* na alimentac¸ão de ovinos e caprinos. Pesquisa Veterinária Brasileira, 32:987-989.

Ross, I.A. (1999). Medicinal plants of the world. In Chemical constituents, traditional and modern medical uses. New Jersey: Humana Press.

Saleh, H.M. (2011). Water hyacinth for phytoremediation of radioactive waste simulate contaminated with cesium and cobalt radionuclides. Nuclear Engineering and Design, 242:425–432.

Saraswat, S. and Rai, J. P. N. (2010). Heavy metal adsorption from aqueous solution using *Eichhornia crassipes* dead biomass, Int. J. Mineral Processing, 94: 203–206.

Satish, S., Raveesha, K.A. and Janardhana, G.R., (1999). Antibacterial activity of plant extracts on phytopathogenic *Xanthomonas campestris* pathovars. Letters in Applied Microbiology, 28:145–147.

Saxena, M., Saxena, J., and Khare, S. (2012). A brief review on: therapeutical values of *Lantana camara* plant. International Journal of Pharmacy and Life Science, 3(3):1551-1554.

Selvi, R.S., Gopalakrishanan, S. and Ramajayam, M. *et al.,* (2010). Evaluation of mucilage of *Prosopis juliflora* as tablet binder. International Journal of Pharmacy and Pharmaceutical Sciences, 2:157-160.

Shanab, S. M., Shalaby, E. A., Lightfoot, D. A., and El-Shemy, H. A. (2010). Allelopathic effects of water hyacinth (*Eichhornia crassipes*), PloS one, 5(10): e13200.

Sharma, O.P., Makar, H.P.S. and Dawra, R.K. (1988). A review of the noxious plant *Lantana camara*. Toxicon, 26:975.

Sharmila, S., Jeyanthi, Rebecca L. and Saduzzaman, M.D. (2013). Biodegradation of Tannery effluent using *Prosopis juliflora*, International Journal of Chem Tech Research, 5(5): 2186-2192.

Silva, D.M., Riet-Correa, F. and Medeiros, R.M.T. *et al.*, (2006). Plantas to´xicas para ruminantes e equ¨´ ìdeos no Serido ′ Ocidental e Oriental do Rio Grande do Norte. Pesquisa Veterinária Brasileira, 26:14.

Silva, M.J., Vale, M.R. and Resumos, V.I. (1991). Reuniao Annual da Federac¸ ao das Sociedades de Biologia Experimental, Caxambu, 296pp.

Simonsen, H.T., Nordskjold, J.B. and Smitt, U.W. *et al.*, (2001). *In vitro* screening of Indian medicinal plants for antiplasmodial activity. Journal of Ethnopharmacology, 74:195–204.

Singh, S. and Swapnil, S. (2011). Antibacterial properties of alkaloid rich fractions obtained from various parts of *Prosopis juliflora*. International Journal of Pharmaceutical Sciences and Research, 2:114–120.

Suksamrarn, A., Chotipong, A. and Suavansri, T., (2004). Antimycobacterial activity and cytotoxicity of flavonoids from the flowers of *Chromolaena odorata*. Archives of Pharmacal Research, 27: 507–511.

Surib-Fakim, A., Swerab, M.D., Gueho, J. and Dullo, E. (1996). Medicinal plants of Rodrigues. International Journal of Pharmacognosy, 34:2–14.

Tabosa, I.M., Riet-Correa, F. and Barros, S.S. *et al.*, (2006). Neurohisto-logic and ultrastructural lesions in cattle experimentally intoxicated with the plant *Prosopis juliflora*. Veterinary Pathology, 43:7.

Taiwo, O.B., Olajide, O.A., Soyannwo, O.O. and Makinde, J.M. (2000). Anti-inflammatory, anti-pyretic and antispasmodic properties of *Chromolaena odorata*, Pharm. Biol. 38:367- 370.

Tan, L., Zhu, D., Zhou, W., Mi, W., Ma, L. and He, W. (2008). Preferring cellulose of Eichhornia crassipes to prepare xanthogenate to other plant materials and its adsorption properties on copper. Bioresource Technology, 99:4460-4466.

Tyagi, S., Ojha, A.C. and Rawat, G.S., (1994). Chemical examination of some medicinal plants of Shiwalik hills. Himalayan chemical and pharmaceutical bulletin,11:4-6.

Varshney, V.K., Gupta, P.K., Naithani, S., Khullar, R., Bhatt, A. and Soni, P.L. (2006). Carboxymethylation of a-cellulose isolated from *Lantana camara* with respect to degree of substitution and rheological behavior. Carbohydrate Polymers, 63: 40–45.

Venkataiah, B., Ramesh, C., Ravindranath, N. and Das, B. (2003). Charminarone, a seco-pseudoguaianolide from *Parthenium hysterophorus*. Phytochemistry, 63:383–386.

Vieira, R.L., Guerra,N.B. and Freitas, E.M. (1995). Coffee substitute from *Prosopis juliflora* DC. Pesquisa Agropecuaria Brasileira, 30:121-124.

Vijayaraghavan, K., Ali, M.S. and Maruthi, R., (2013). Studies on phytochemical screening and antioxidant activity of *Chromolaena odorata* and Annona squamosa. International Journal of Innovative Research in Science, Engineering and Technology, 2:7315-7321.

Yadav, R., Tikar, S.N. and Sharma, A.K. *et al.*, (2015). Screening of some weeds for larvicidal activity against Aedes albopictus, a vector of dengue and chikungunya. Journal of Vector Diseases, 52:7

Yadav, R., Tyagi, V., Tikar and S.N. *et al.*, (2014). Differential larval toxicity and oviposition altering activity of some indigenous plant extracts against dengue and chikungunya vector Aedes albopictus. Iran. Journal of Arthropod-Borne Diseases, 8:174-185.

Zhang, S.M., He, Y.S., Tabba, H.D. and Smith, K.M. (1988). Inhibitor against the human immunodeficiency virus in aqueous extracts of Alternanthera philoxeroides. Chinese Medical Journal, 101: 861-866.

8 BIO- ENERGY AND UTILIZATION OF INVASIVE ALIEN SPECIES

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INTRODUCTION

An invasive plant species refers to the species that is non-native to that ecosystem, which grows aggressively, spreads very quickly, and displaces other plants from that locality. The invasive plants have major impact on the habitat and species diversity. They cause loss of biodiversity including species extinctions, and changes in hydrology and ecosystem function (Lowe *et al.,* 2000). Invasive plants have high tolerance against environmental extremes and greater adaptability in wide range of environmental conditions (Raghubanshi *et al.,* 2005). These plants can survive and dominate the habitat in almost any environmental condition. Invasive plants mostly have high water, light and nutrient use efficiencies. They have zero or very short dormancy period, high productivity and high reproductive potential (Tucker and Richardson, 1995; Raghubanshi *et al.*, 2005).

Lantana camara is an invasive weed species which stunt the growth of other surrounding plants and thereby adversely impacts and eliminate important native plant species. Native to South, Central America and the Caribbean islands, *L. camara* was brought to India as an ornamental plant by British, possibly as long as 200 years ago (Baars, 2002). *L. camara* is an aggressive, vigorously growing plant that tolerates wide variety of environmental conditions, and is available in different regions across India. Being highly ecologically tolerant and adaptable species it is widely available and distributed in distinct geographical areas. But more than the widespread and diverse distribution it is the density of infestation within the range that has been recognized as future threat to ecosystem (Sharma *et al.*, 2005). There are several control measures employed to curtail the infestation of Lantana in India, but none have been able to completely curb the infestation. The mechanical methods are more effective in smaller areas and require complete removal of rootstocks while weeding (Babu *et al.*, 2009). Several chemical (Achhireddy *et al.,* 1985; Sharma *et al.,* 1988) and biological control methods (Matthew and Adele, 2007) have been suggested by researchers, but a comprehensive and effective control programe which is feasible and cost effective is still awaited. There are several reported uses of *L. camara.* It is used for making furniture's, toys and house hold articles (Kannan *et al.,* 2008). The furniture made out of Lantana is found to be long lasting and less likely to be eaten by termites. *L. camara* is also successfully used for making wood polymer composites (Kale *et al.*, 2017), pulping and paper making (Ray *et al.,* 2006; Naithani and Pande, 2009; Bhatt *et al.*, 2011), herbal medicine use (Ghisalberti 2000; Sharma *et al.* 1999) etc.

Prosopis juliflora is grows as shrub or small tree (El-Keblawy and Al-Rawai 2007) and native to Mexico, South America and the Caribbean. *P. juliflora* grows in most soils and water condition including; sandy, rocky, poor and saline soils. There are several uses reported from *P. juliflora.* The pods are used as food and medicinal supplement for man and animal (Maundu *et al.,* 2009). The alkaloids obtained from leaves of *P. juliflora* are reported to have antifungal properties. Wood of this species used as firewood, charcoal and activated carbon production (Kailappan *et al.*, 2000). *L. camara* and *P. juliflora* are widely available weed species and are reported to as potential biomass sources (Murali and Shetty 2001). One of the ways to make effective use of these invasive forest weed is to utilize them as a source of energy.

Today, the bioenergy has been entered into a new phase of high importance and visibility with climate change and energy security concerns. Biomass is considered as a carbon neutral and socially viable source of renewable energy, with a condition that it should arise from sustainably managed resources (forests, trees outside forests, etc.). Biomass fuels consist of both woody and non-woody biomass which can either be burned directly in a furnace or can be converted into high energy content fuels.

FUEL WOOD PROPERTIES

The quality of a fuel depends on basic properties of the raw material. Several types of biomass are used as energy conversion feedstocks, including wood, agricultural and forest residues, municipal solid waste and industrial waste etc. Depending upon the physical and chemical characteristics, the biomass can be categoried in four different types i.e., wood, herbaceous plants including grasses, aquatic plant and manures (McKendry, 2002). The chemical and physical property of the feedstock determines the form of energy (end product) and also directs the selection of energy conversion process (Sofer and Zaborsky, 1981). The basic fuel properties include moisture content, calorific value, density, volatile, ash and fixed carbon content and alkali metal content. It also includes the determination of cellulose, hemicellulose, lignin and extractive content in biomass. Density is one of the important parameters that directly affect the fuel quality of a feed stock. The species having higher density are preferred as fuel because of high energy content per unit volume and their slow burning property. The density of *L. camara* biomass ranged from 0.497 to 0.520 g/cm^3 (Table 1) (Kumar *et al.,* 2009). *P. juliflora* wood has high density (0.9 g/cm^3), which gives added advantage to this species (Kumar and Chandrashekar 2016). The calorific value is considered as an important parameter for comparing one fuel with another. The variations in the calorific value of different biomass fuel indicate the differences in their chemical and elemental composition. The calorific values of lantana stem, twigs and leaves were found to be 19.6, 19.5 and 17.1 MJ kg-1, respectively (Table. 1)(Kumar *et al.,* 2009). Among the two weed species, a comparatively higher calorific value i.e., 21.0 MJ kg-1 was reported in *P. juliflora*. The higher calorific value in *P. juliflora* was attributed to the presence of high lignin and fixed carbon content (Kumar and Chandrashekar, 2016).

The amount and quality of ash in the biomass is other important fuel parameters. Ash is produced by the chemical breakdown of biomass by combustion in air. The amount of ash present in biomass differs with the plant component (Senelwa *et al.* 1999; Kataki and Konwer, 2002). The bark and the leaves are found to have more ash content as compared to the wood. The ash content of the biomass affects both handing and processing cost of the overall, biomass energy conversion cost (Rhena, 2007). The ash formed inside the furnace results in various problems like slagging, fouling, sintering and corrosion. The amount of ash present in wood varies from 1-3%. The ash percentage of lantana stem, twigs and leaves were found to be 0.85%, 1.34% and 7.55%, respectively (Table 1). Among the two weed species a higher percentage of ash was observed in *P. juliflora* (1.43%). The values of volatile matter were reported to be around 73.49% and 74.42% in twigs and stems of lantana, respectively. The fixed carbon in both the weed species ranged from 17.36 % to 25.5% and its values were found to be higher in *P. juliflora* i.e., 25.5%. The fuel properties and the woody nature of both the weed species makes them suitable for thermochemical energy conversion.

Table 1. *Physico-chemical properties, proximate and ultimate analysis and high heating value of Lantana camara*

Biomass feedstock	Ultimate analysis					Proximate analysis				BD (gm/cm3)	HHV (MJ/kg) dry weight)	Holo-cellulose (% oven	Lignin (% oven dry weight)
	C (%)	H (%)	N (%)	S (%)	O* (%)	MC (%)	Ash (%)	VMC (%)	FCC (%)				
Lantana (Stem)	48.1	6.2	1.0	0.1	43.6	7.0	0.9	74.4	17.7	0.5	19.6	81.5	20.1
Lantana (Twig)	45.9	6.9	1.0	0.1	44.6	7.8	1.3	73.5	17.4	0.5	19.5	ND	ND
Lantana (Leaves)	43.0	5.7	1.0	0.1	42.5	7.5	7.6	67.5	17.5	ND	17.1	46.2	30.2
P. juliflora	49.3	5.6	0.1	0.1	44.8	5.7	1.4	67.0	25.5	0.9	21.0	71.1	27.3

HHV-higher heating value, MC-moisture content, VMC-volatile matter content, FCC-fixed carbon content, BD-basic density
ND-not determined
** Calculated by difference method*

BRIQUETTING OF *L. CAMARA*

Briquetting of biomass presents a possible avenue for the large scale and sustainable utilization of waste biomass resources for energy production. There is enormous opportunity for the rural communities to utilize the waste biomass material available in there vicinity. The success of briquetting programme basically depends upon three important factors i.e., availability of raw material, adequate technology and market for briquettes. The appropriate biomass for briquetting purpose should have less moisture content, less ash content and high calorific value. The biomass obtained from *L. camara* is difficult to use in its original form because of high moisture content, irregular shape and sizes etc. The densification of biomass materials, known as briquetting; it not only improve the energy efficiency of biomass resources but also facilitates easy transportation, handling and storage. Industries such as textile, hotels, tea processing, leather, and solvent oil extraction

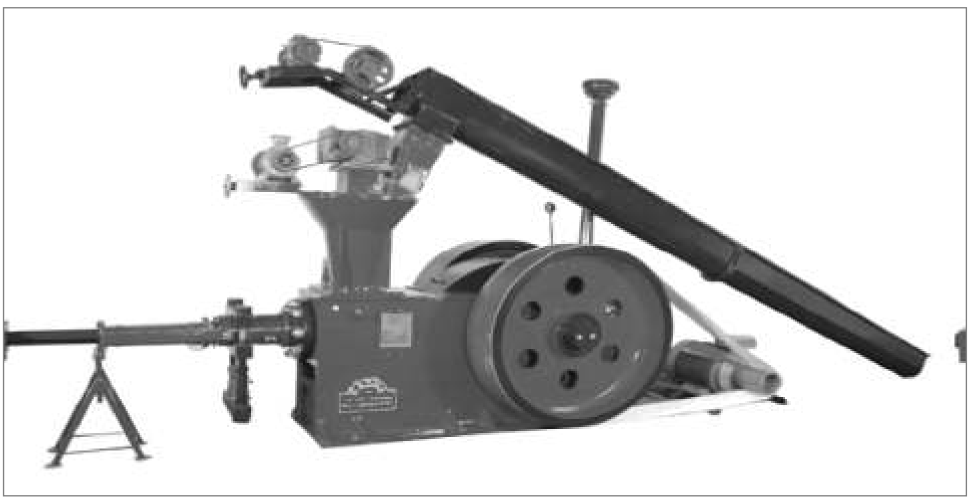

Fig 1. *Biomass Briquetting Machine*

plants, chemical and related industries are the potential users of biomass briquettes. In fact, the demand of briquettes is many times higher than its supply (Shekhar, 2011).


Fig 2. *Biomass Briquettes*

There are two different types of technologies used for biomass briquetting. In first one the biomass is initially heated or torrefied, and then mixed with certain binders before densification. Using this technology the air dried lantana biomass is initially loaded in kiln or furnace and heated under oxygen free environment at 400°-500°C for 1 to 2 hours. The charcoal thus obtained is powdered and used for making briquettes. The binder is prepared out of starch and water solution, mixed in the ratio of 10:1. The solution is heated for 15 min and cooled for usage. The powdered charcoal is mixed with the binder and the briquettes are made either with hand or with machine. Many other biomass wastes like coconut shell, coffee husk, rice husk, cotton stalk, wood waste etc. can be carbonized and used along with lantana charcoal for the purpose of briquetting.

The second technology involves direct densification of biomass i.e., without use of any binder. This is also known as high compaction technology. In this technology, the biomass is initially converted into desired particle size which is then compressed in a die by a reciprocating ram at very high pressure. Most of the briquetting industries operating in India are of high compaction technology (piston press screw press). The commercial briquetting industries produce 60 or 90mm external diameter briquettes at production capacity of 1.5 to 2.0 tons per hour. *L. camara* biomass (twigs and stem) are very much suitable for the purpose of briquetting. The powdered lantana biomass when subjected to heat and pressure in the die forms very good quality briquettes without any binding material. The hemicellulose and lignin present in the lantana biomass hydrolyses into lower molecular carbohydrates and lignin products under high pressure and steam condition. The wood fibers also gets softens due to the effect of steaming. When the relaxed and heated material passes through the die, the hemicellulose and lignin acts as adhesive and provides in-situ binding. The required temperature in the die should be around 280°C. Any temperature beyond 300°C may cause decomposition of the material.

Charcoal from *P. juliflora* and *L. camara*

Historically, wood is oldest form of energy feedstock used by mankind. Wood is either burned directly as firewood or indirectly as charcoal (Matti, 2004). Firewood is usually bulky and causes many problems during transportation. The conversion of wood into charcoal increases the energy and economic value of the wood. Depending upon the soaking time and temperature pyrolysis (charcoal making process) can be classified under slow, intermediate or fast pyrolysis. The charcoal obtained from slow pyrolysis is mainly used for cooking and heating as a domestic fuel (Fuwape, 1993). The other application of such charcoal includes water purification, food industry, pharmaceutical industry, chemical industry, metallurgical industry etc (Muylaert *et al.* 1999). At elevated temperature (500-700 ^{0}C) and higher heating rate (fast pyrolysis) the product that is obtained contains more liquid material (bio-oil) rather than solid charcoal (Han and Kim, 2008). The bio-oil obtained is invariably complex mixtures of hydrocarbon, ketones, aldehydes and other organic compound (Park *et al.,* 1998). Fast pyrolysis is a successful way of converting solid biomass into an easy to store and transportable liquid, which can be used for production of heat, power and chemicals (Saikia *et al.*, 2007). Wood charcoal is porous and can adsorb liquids and gases on its porous surface. Therefore, it is used in water filters, gas masks and antigastric tablets for people suffering from indigestion. Charcoal is also used as a decolorizing agent for decolorizing sugar solutions, organic preparations, alcohol and petroleum products. The demand of charcoal has increased greatly in recent past due to multiple uses of charcoal.

P. juliflora wood is a major energy source for rural household throughout the world. The wood of *P. juliflora* burns evenly and not much smoke is produced during its combustion. It can be easily converted into solid, liquid and gaseous fuel (Silva *et al.*, 2011). The charcoal making process is affected by heating rate, residence time, particle size, chemical composition, moisture content of lignocellulosic material and final pyrolytic temperature (Kumar *et al.* 1992; Degroot and Shafizadeh 1984). *P. juliflora* wood makes excellent charcoal. *P. juliflora* wood has high calorific value (21MJ/kg), high fixed carbon content (25%) and low ash content (1.7%) wood. Ash elemental analysis shows the presence of high calcium (68%) and low silica content (1%). Presence of high lignin content (25%) in *P. juliflora* wood makes it a suitable raw material for charcoal production. Effects of carbonization temperature on yield and other fuel properties of *P. juliflora* wood charcoal were investigated by Kumar and Chandrashekar 2016. The result shows that charcoal yield and its properties are greatly influenced by carbonization temperature. The charcoal yield in *P. juliflora* reduced from 49 to 34%, when carbonization temperature was increased from 300^{0}C to 800^{0}C. Fixed carbon content, ash content and calorific value of charcoal ranged between 55-84%, 2-4% and 24-33 MJ?kg-1, respectively. The highest calorific value (32.8 MJ/kg) was found in charcoal obtained at 600^{0}C. The yield of charcoal at 600^{0}C was found to be 37%. In *Lantana,* the yield of charcoal decreased from 38.8% to 25.3 % when the carbonization temperature was increased from 300 ^{0}C to 800^{0}C. The highest calorific value (31.74 MJ/kg) was recorded in charcoal obtained at 600^{0}C (Kumar and Chandrashekar, 2013).

In India, charcoal manufacturing from *P. juliflora* forms an integral part of daily activity of a large part of the rural population. Revenue earned from charcoal manufacture plays a vital role in rural livelihoods of these areas. Pasiecznik *et al.*, 2001, reported that in case of *P. juliflora* a high quality charcoal can be easily produced from green wood as it is from dried wood. They found that traditional earth kiln method may yield 1 to 2 kg of charcoal from 10 kg of green wood in 2 to 4 days. The harvested wood is initially segregated into similar diameter trunk or branches. The wood pieces are then stalked and sprayed over with little bit of moisture to avoid complete combustion. The final restriction to the oxygen is by covering the entire stalk with mud. Earthen kiln is fired and the slow burning continues for 3 to 8 days depending upon size of stalk. After completion of the burning process the stalk is opened and charcoal is removed from the kiln. Finally the charcoal is graded and packed for the sale. In such traditional earth kilns charcoal can be produced at minimum cost. The earth mounds are erected at the site of harvest, therefore little or no transportation cost is required. This traditional method doesn’t require large investments and the labor associated with charcoal production is cheaply available in the area. Moreover, production size is not a limit. There is well established market channel that begins at the production site and ends at the consumers door step (Kwaschik, 2008).

GASIFICATION

India has an estimated renewable energy potential of about 25 GW from biomass energy of which around 17536 MW is being produced (MNRE, 2019). Even though the biomass gasification is a well adopted technology throughout the world, its utilization for power generation in India is relatively less. About 150 MW equivalent biomass gasifier systems have been set up for grid and off-grid projects. More than 300 rice mills and other industries are using gasifier systems for meeting their captive power and thermal applications. In addition, about biomass gasifier 70 systems are providing electricity to more than 230 villages in the country (MNRE, 2019).

Biomass gasification is thermochemical conversion of lignocellulosic biomass into combustible gases. Biomass gasifier is a reactor in which biomass undergoes the process of drying, pyrolysis, oxidation and reduction reaction in restricted oxygen condition to yield a mixture of gases (produce gas). The gas produced consists of carbon monoxide, hydrogen and methane, and diluents such as carbon dioxide and nitrogen. *L. camara* and *P. juliflora* are wood biomass having high volatile content and fixed carbon content. This biomass material can be very well utilised as source for biomass gasification.

REFERENCES

Achhireddy, N.R., Singh, M., Achhireddy, L.L., Nigg, H.N. and, Nagy, S. (1985). Isolation and partial characterization of phytotoxic compounds from Lantana (*Lantana camara* L.). Journal of Chemical Ecology, 11: 979–988.

Baars, J.R. (2002). Biological control initiatives against *Lantana camar*a L. (Verbenaceae) in South Africa: an assessment of the present status of the programme, and an evaluation of *Coelocephalapion camarae* Kissinger (Coleoptera: Brentidae) and *Falconia intermedia* (Distant) (Heteroptera: Miridae), two new candidate natural enemies for release on the weed. PhD thesis, Rhodes University, Grahamstown, South Africa.

Babu, S.,Love, A. and Babu, C.R. (2009). Ecological Restoration of Lantana-Invaded Landscapes in Corbett Tiger Reserve, India. Ecological Restoration, 27(4):467-477.

Bhatt, N., Gupta, P.K. and Naithani, S. (2011). Ceric-induced grafting of Acrylonitrile onto Alpha Cellulose isolated from *Lantana camara.* Cellulose Chemistry and Technology, 45 (5-6): 321-327.

Degroot, W.F. and Shafizadeh, (1984). Kinetics of gasification of Douglas Fir and cottonwood chars by CO2. Fuel, 63: 210-216.

El-Keblawy, A. and Al-Rawai, A.(2007). Impacts of the invasive exotic *Prosopis juliflora* (Sw.) D.C. on the native flora and soils of the UAE, Plant Ecol, 190 (1): 23-35.

Fuwape, J.A. (1993). Charcoal and fuel value of agroforestry tree crops, Agroforestry System, 22: 55-59.

Ghisalberti, E.L. (2000). *Lantana camara* Linn. (Review). Fitoterapia, 71: 467–485.

Han, J. and Kim, H. (2008). The reduction and control technology of tar during biomass gasification/pyrolysis: An overview, Renew. Sust. Energy Rev, 12: 397–416.

Kailappan, R., Gothandapani, L. and Viswanathan, R. (2000). Production of activated carbon from prosopis *(Prosopis juliflora)*, Bioresource Technology, 75 (3): 241-243.

Kale, A., Raghu, N., Chauhan, S.S. and Aggarwal, P. (2017). *Lantana* Fiber-Filled Polypropylene Composite, Wood is Good, 10.,343-351.

Kannan, R., Aravind, N.A., Joseph, G., Ganeshaiah, K.N. and Shaanker, R.U. (2008). Lantana Craft: A Weed for a Need. Biotech News, 3(2): 9-11.

Kataki, R. and Konwer, D. (2002). Woodfuel characteristics of indigenous tree species of North East India. Biomass and Bioenergy, 22:433-437.

Kumar, M., Gupta, R.C. and Sharma, T. (1992). Effect of carbonisation conditions on the yield and chemical composition of Acacia and Eucalyptus wood chars, Biomass and Bioenergy 3:411-417.

Kumar, R. and Chandrashekar, N. (2016). Study on fuelwood and carbonization characteristics of *Prosopis juliflora,* Journal of the Indian Academy of Wood Science, 13: 101–107.

Kumar, R., Chandrashekar, N., and Pandey, K.K. (2009). Study on fuel properties and combustion characteristic of *Lantana camara* and Eupatorium spp., Current Science 97(6):930-934.

Lowe S., Browne M., Boudjelas S. and De Poorter M. (2000). 100 of the World's Worst Invasive Alien Species A selection from the Global Invasive Species Database. Published by The Invasive Species Specialist Group (ISSG) a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN), 12pp.

Matthew, B. T. and Adele, M. R (2007). Are exotic natural enemies an effective way of controlling invasive plants, TRENDS in Ecology and Evolution, 22 (9):447-452.

Matti, P. (2004). Global biomass fuel resources, Biomass and Bioenergy, 27: 613-620.

Maundu, P., Kibet, S., Morimoto, Y., Imbumi, M. and Adeka, R. (2009). Impact of *Prosopis juliflora* on Kenya's semi-arid and arid ecosystems and local livelihoods, *Biodiversity, 10 (2-3):33-50.*

McKendry, P. (2002).Energy production from biomass, Overview of biomass, Bioresour. Technol, 83: 37-46.

MNRE (Ministry of New and Renewable Energy), India, annual report, available at (https://mnre.gov.in/file-manager/annual-report/2014-2015/EN/Chapter%201/chapter_1.htm) assessed on 21st January, 2019.

Murali, K.S. and Setty, R.S. (2001) ; Effect of weeds *Lantana camara* and *Chromolaena odorata* growth on the species diversity, regeneration and stem density of tree and shrub layer in BRT sanctuary. Current Science, 80 (5): 675-678.

Muylaert, M.S., Sala, J. and Vasconcelos de Freitas, M.A. (1999). The charcoal production in Brazil- Process efficiency and environmental effect, Renewable Energy 16: 1037-1040.

Naithani, S. and Pande, P.K. (2009). Evaluation of *Lantana camara* Linn. stem for pulp and paper making. Indian Forester, 135 (8): 1081-1087.

Park, S.B., Kwon, S.D. and Ahn, K.M. (1998). Development of new uses of bamboos III: Studies on general properties of bamboo charcoal, FRI J. Forest Sci, 59:25–35.

Pasiecznik, N.M., Felker, P., Harris, P.J.C., Harsh, L.N., Cruz, G., Tewari, J.C., Cadoret, K., Maldonado, L.J. (2001). The *Prosopis juliflora* – Prosopis pallida Complex: A Monograph. HDRA, Coventry, UK. P. 172.

Raghubanshi A. S., L. C. Rai, J. P. Gaur and J. S. Singh (2005). Invasive alien species and biodiversity in India. Report on workshop in the Department of Botany, Banaras Hindu University during 18–20 August 2004 to discuss various aspects relating to alien invasive species and biodiversity in India. Current Science, 88 (4), 25: 539-540.

Ray, A.K. and Puri, M.K. (2006). Modeling H Factor-Kappa Number for Kraft Pulping of *Lantana camara* Plant- An Experimental Investigation. Advances in BioCatalytics and Protein Engineering, 15: 1–62.

Rhena, C., Ohmanb, M., Grefa, R. and Wasterlunda, I. (2007). Effect of raw material composition in woody biomass pellets on combustion characteristics. Biomass Bioenergy, 31:66–72.

Saikia, P., Kataki, R., Choudhury, P.K. and Konwer, D. (2007). Carbonization of eight bamboo species of northeast India, Energy Sources, 29: 799? 805.

Senelwa, K.Sims, and Ralph, E.H. (1999).Fuel characteristics of short run rotation forest biomass, Biomass and Energy, (17):127-140.

Sharma, G.P., Raghubanshi, A.S. and Singh, J.S. (2005). Lantana invasion: An overview. Weed Biology

Sharma, O.P., Makkar, H.P.S. and Dawra, RK. (1988). A review of the noxious plant *Lantana camara.* Toxicon, 26: 975–987.

Sharma, S., Singh, A. and Sharma, O.P. (1999). An improved procedure for isolation and purification of lantadene A, the bioactive pentacyclic triterpenoid from *Lantana camara* leaves, Journal of Medicinal and Aromatic Plant Science, 21: 686–688.

Shekhar, N. (2011). Popularization of Biomass Briquettes- A means for Sustainable rural Development, Asian Journal of Management Research, 2 (1): 457-473.

Silva, C., Andrade, S., Schuler, A., Souza, E., and Stamford, T. (2011). Production of Ethanol form Mesquite [*Prosopis juliflora* (SW) D.C] Pods Mash by *Zymomonas mobilis* in Submerged Fermentation. Sci. Agric. (Piracicaba, Braz.), 68 (1):124-127.

Sofer, S.S., and Zaborsky, O.R. (1981). Biomass conversion processes for energy and fuels.

Tucker K.C and Richardson D. M. (1995). An expert system for screening potentially invasive alien plants in South African fynbos. Journal of Environment Management 44(4): 309:338.

9 MANAGEMENT OF SELECTED INVASIVE ALIEN PLANT SPECIES AND RESTORATION OF INVADED HABITATS

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INTRODUCTION

Invasive Alien Species can have harmful impacts on biodiversity, excluding or limiting many native species and significantly altering ecosystems (Early *et al.*, 2016). Exotic species have impacts on the recipient ecosystem simply by their presence (i.e., on the availability of space, food, water, or other resources of other species; Russell and Blackburn, 2017). As a result, the introduction of all IAS should be prevented while the spread and proliferation of all established IAS should be managed (Epstein, 2017). The management of previously introduced or established IAS is often time consuming, costly and challenging (Courchamp *et al.*, 2017). Further due to limited resources available to the environmental managers some sort of prioritization process on invasive alien species to be managed is obvious. Moreover, in order to practice best strategies to manage IAS impact as a whole, objective and clear prioritization processes are needed (McGeoch *et al.*, 2016).

Rapid response for the IAS management strategy greatly increases likelihood of success (Early *et al.*, 2016). Therefore, for the early detection of the problematic invasive species proper monitoring is required. Monitoring can be done by qualitative approach like species inventory and quantitative approach using phyto-sociological methods and mapping using ground-based methods. There is a need for effective planning on reports of infestations of new and naturalized weeds and early detection by plant detection network. However, better biosecurity legislation, and enforcement is needed to halt IAS introductions, across the world (Simberloff *et al.*, 2003; Genovesi *et al.*, 2015). It is important that we must consider the less subjective issue of what management is actually feasible- the likely effectiveness, practicality, risk, cost, impact, and timeframe of management options (Epstein, 2017). The management practices are species as well as locality specific, often gives limited results. Thus an integrated approach has to be adopted to manage invasion of alien plant species effectively. Therefore, this chapter reviews various control, management and restoration options of important Invasive Alien Plant Species (IAPS) in India.

MANAGEMENT OPTIONS

There are broadly three types of methods used for the control or eradication one is the Physical method in which invader plants are removed by machine or people mechanically. Burning is another physical control method which is used in many places, but the major disadvantage of this method is that the burnt residues left in the fields degrades soil quality and therefore this technique is not recommended (Singh *et al.*, 2003). Second is the Chemical method in which herbicides are used to kill invader plants and third one is the Biological method where predators or pathogens are used to control the invading plant’s reproduction (Geesing *et al.*, 2004). According to CAB International for Global Invasive Species Program (GISP) there are three major management options for alien species management which are prevention, early detection, and eradication (Wittenberg and Cock, 2001).

Prevention

Prevention is the first and mainly a cost-effective option of defense, using tools such as:

- Public information.
- "Early warning", the capability to predict potential new invasion sites for an invasive species, and/or predict potential new invasive species for a region or site.
- Risk assessments and environmental impact assessments.
- National and international regulations on prevention measures and their enforcement with inspections and fees.
- Treatment of imported commodities, including through fumigation, immersion, spraying, heat and cold treatment, and pressure.
- As a last resort, trade restriction or prohibition consistent with the WTO Sanitary and Phytosanitary Agreement.

Listing of Species:

Listing of species is one effective tool for dealing with IAS issues (Wittenberg, *et al.*, 2001; Shine, *et al.*, 2005) and is an important first step in prevention of those alien species that may become invasive and further require special attention (Mc Neely *et al.,* 2001). Such lists can include:

- Black lists: Species known to be invasive and so destructive that their introduction should be prohibited.
- White lists: Species known on the basis of stringent criteria to have such a low probability of invasion that they can be introduced.
- Grey lists: The great majority of species whose probability of becoming invasive is unknown.

Mitigation:

Mitigation include following steps-

- Eradication (eliminating the IAS completely);
- Containment (keeping the IAS within regional barriers); or
- Suppression (reducing population levels of the IAS to an acceptable threshold).

Early detection concentrates on a concern species. Species-specific surveys are designed and adapted for a specific situation considering the ecology of target species. Site-specific surveys can identify invaders near high-risk areas or in biodiversity rich areas. However when prevention fails, eradication is the only option. The aim of eradication is to reduce the density of IAS below the acceptable threshold level (Mandal, 2011).

Eradication

Previously eradication was continuously being realized as an easy approach to manually remove the invasive plants (Rai, 2013). However eradication alone would not allow ecosystems to recover because some invaders alter the habitat conditions as a result it becomes unsuitable for native species (Zavaleta *et al.*, 2001; Rai, 2013). For example in the Middle East to the western USA high soil salinity is caused by the invasive ice plant *Mesembryanthemum crystallinum* and Tamarix spp., which makes it difficult for salt-sensitive native species to re-establish (El-Ghareeb, 1991; Zavaleta *et al.,* 2001). In such cases, eradication must be followed by additional site restoration (Zavaleta *et al.,* 2001; Rai, 2013). Further invasive plant species removal in isolation can also result in unexpected changes to other ecosystem components (Rai, 2013). As the numbers of interacting invaders increase in ecosystems these secondary effects will become more likely and exotics in late stages of invasion replace their functional roles and eliminate native species (Zavaleta *et al.*, 2001; Rai, 2013). Integration of eradication along with holistic assessment and restoration process will help safeguard against accidental adverse effects on native ecosystems (Zavaleta *et al.*, 2001; Rai, 2013). Hence the best solution is to prevent the introduction of invasive species but once naturalized eradication will be difficult.

CONTROL MEASURES

Invasive plant control methods are mainly divided into following categories: mechanical, chemical, biological, cultural techniques, habitat management and integrated pest management (McNeely *et al.*, 2001; Wittenberg *et al.*, 2001). Given the high complexity of the ecology of invasive species and habitats affected, control measures need to be applied with the fullest possible scientific understanding.

- Mechanical control are used extensively by staff and volunteers; they include: hand pulling, weed wrench, cutting (high and low, in the case of climber/lianas), mowing, digging, bush hogging, prescribed burning, brush cutting and weed whipping, and pulling with a tractor and chain or Brush. This method involves directly removing the species by hand or with appropriate machines such as harvesting vehicles (e.g., for water hyacinth) or firearms (e.g., for large mammals), or traps (for animals). These methods are effective if repeated frequently during a growing season to exhaust a plant's root reserves, or if used in combination with other techniques.
- Chemical control involves the use of herbicides, insecticides, and rodenticides that primarily affect the target species, are delivered in a way that avoids the potential problem of resistance developing over time, and do not accumulate in the food chain. The development of pesticide-resistant strains of pests, diseases and weeds may reduce the effectiveness of the chemical management option for their control. The decision to use chemical controls is a carefully considered one. The exclusive use of herbicides alone is not likely to be an effective long-term solution for controlling invasive species. Difficulties include controlling only target plants at the correct time during their life cycle, and the potential health risks to workers and the environment. Herbicides need to be applied only by trained and licensed personnel. In combination with physical methods of reducing the above-ground portion of a plant, herbicides may limit resprouting or effectively control plants when used in combination with other techniques. Typically herbicides are used in small quantities for a stump application immediately after an invasive is cut back, or they are used to control resprouts some time after the cutting. The environmental damage from invasive plants is considered to be greater than the risk associated with the use of non-persistent herbicides.
- Biological control involves the intentional use of populations of natural enemies of the target invasive alien species or other methods that include, for example, mass release of sterile males of the target species, inducing resistance in the host against the IAS that is attacking it, or releasing a natural enemy to control the IAS. It is essential to ensure that the species used for biological control does not in turn become itself invasive. The risks associated with species introduction are high and only well funded and thoughtfully researched programs are effective.
- Cultural control loosely describes changes to the structure or nutrient availability of a site to create conditions that do not favour invasive plants. This form of control includes: minimizing the edge habitats that are prone to invasion, amending soil to tie up excess nutrients, or, for example, removing multiflora rose from a habitat as a way of preventing it from serving as a ladder for lianas, preventing access to control other invasive plants, replanting with a diversity of desirable species so that they can shade out invasive species.
- Habitat management involves actions such as prescribed burning, grazing, and other activities (Mc Neely *et al*.,2001).
- Integrated Pest Management (IPM) involves a combination of the methods described above, based on ecological research, regular monitoring, and careful coordination. IPM is likely to achieve the best results in many situations (Wittenberg and Cock, 2001); (Mc Neely *et al*.,2001).

In order to illustrate feasible management practices to reduce negative impacts on our biodiversity, a brief description of different management practices for some important Invasive alien plant species of India are discussed in this chapter.

Acacia mearnsii De Wild. (Family: Fabaceae; Subfamily: Mimosoideae)

Other Scientific Names:	*Acacia decurrens* var. mollis (Wendl.) Willd., *Acacia decurrens* var. mollis Lindl. (Wendl.) Willd., *Acacia mollissima* auct., *Racosperma mearnsii* (De Wild.) Pedley
Vernacular names:	Tamil- Chavuku; English-Green wattle, Tan wattle, *Australian acacia,* Black wattle, late black wattle
Common name:	Black wattle

Acacia mearnsii is one of the fast growing leguminous trees of highland tropics (above 600m) widely used as a source of tannin, resins, timber, fuel wood, pulp wood, charcoal, poles and green manure.

Acacia mearnsii De Wild. *(Photo credit: Dr SP Subramani, IFGTB)*

- Distribution: *Acacia mearnsii* is a native of south-east Australia and it has been introduced into 25 countries in the tropical and subtropical regions of the globe. In India, it is reported from Andhra Pradesh, Arunachal Pradesh, Assam, Himachal Pradesh, Jammu and Kashmir, Karnataka, Kerala, Maharashtra, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tamil Nadu, Tripura, Uttarakhand and West Bengal (CABI, 2005; 2019; Chandra, 2012).
- Description: *A. mearnsii* is a large shrub or small evergreen tree, 5-15 (20) m tall with dark olive-green, finely hairy, bipinnate; leaflets short (1.5 - 4mm) and crowded; raised glands occur at and between the junctions of pinnae pairs. Flowers are pale yellow or cream, globular flower heads in large, fragrant sprays. Fruits are dark brown pods, finely hairy, usually markedly constricted (Henderson, 1995).
- Management: Black wattle competes and replaces indigenous vegetation including grass communities and reduces carrying capacity of the land. Hence effective management practices to control its invasion are required. Following are some control measures;
- Mechanical control: *Acacia mearnsii* sprouts from the roots, hence this should be removed (Weber, 2003) along with girdling.

- Seedlings/Saplings can be annually pluck and remove
- Medium sized trees can be cut at 0.5 m above the ground level and apply Glyphosate (45% v/v) at the cut surface within 30 seconds and
- Large trees can be simply cut from the base of tree or Remove the bark from collar region up to 50 cm height (Weber, 2003).

- Chemical control: Chemical control measures of black wattle include treatment of the saplings with herbicides such as triclopyr, glyphosate, dicamba and picloram on cut-surface. In large trees, herbicides may have to be applied through drilled holes. Basal bark and stump bark treatments with herbicides are also effective. Biological control of the tree has been attempted in South Africa by introducing a seed-eating weevil *Melanterius maculatus* which caused reductions in seed numbers. A Cecidomyiid gall midge, D*asineura* sp., has also been identified as a promising bio-control agent in South Africa as it forms flower galls and prevent fruit production without affecting vegetative growth (CABI, 2019).
- Biological Control: Seed feeders and a mycoherbicide are used to control *A. mearnsii* (Henderson 2001). Agricultural Research Council, Plant Protection Research Institute (ARC) South Africa (2000) names two agents that it supplies for the purpose of biological control in South Africa; the seed weevil *Melanterius maculatus* and a native South African fungus *Cylindrobasidium laeve* that attacks stumps and is applied after felling to prevent resprouting. Recently a cecidomyiid midge, which forms galls in the flowers and prevents pod development was released (Impson *et al.*, 2008). Impson *et al.*, (2013) reported that while this flower-galling midge reduces seed set to very low levels, it does not negatively affect growth of the tree and so will have no detrimental effect on the wattle forestry industry in South Africa.

Ageratum houstonianum Mill. (Family: Asteraceae)

Other Scientific Names: *Ageratum mexicanum* Sims.

Vernacular names: Assamese-Gendali-bon; Hindi- Visadodi

Common name: Blue billy goat weed

Ageratum houstonianum Mill. *(Photo credit: Dr. A. Rajasekaran, IFGTB)*

- Distribution: *Ageratum houstonianum* is an annual herb native to Mexico and Central America and it was brought to Europe shortly after its discovery, where its use as an ornamental started (Johnson, 1971). In India, it is distributed in Himachal Pradesh, Uttarakhand, Kerala, Tamil Nadu, Karnataka, Maharashtra, Rajasthan, Delhi, West Bengal and Jammu & Kashmir (Soure: efloraofindia).
- Description: *Ageratum houstonianum* is reported to be a weed and invasive outside its native range, due to its high production of small seeds with easy dispersal by wind or water (BioNet-EAFRINET, 2016).This species is a short-lived (annual or biennial) herbaceous plant growing 0.3-1 m tall, with showy flower-heads. *A. houstonianum* mainly found in naturalized farmlands, wastelands, roadsides, forest trails, crops, riverbanks and wetlands.
- Management: The dense ground cover and colonies of *A. houstonianum* can exclude the growth of other species, causing changes in the species composition and reducing species richness (Barua *et al.*, 2013). It also has shown allelopathic effects on the germination and growth of other species (BioNet-EAFRINET, 2016). Some control and management practices are discussed below;
- Mechanical and Chemical controls: *Ageratum houstonianum* plants can easily be uprooted by mechanical or manual means but their removal by hand is not feasible. The herbicide diphenamid, applied to the soil reduces the growth of the species (Adamson and Crossley, 1968). Application of Atrazine 1.5 kg ha-1 on emerging plants at their 2 - 3 leaf stage in May-June and or September-October by spray or broadcast application after mixing with 150 kg sand in grassland or pastures will be more effective. Application of glyphosate 1.5 kg ha-1 in 800 L water in May-June and September-October will be effective on old Ageratum plants before flowering (Angiras, 1998). Application of the herbicide Dicamba and 2,4-D cause visible foliar injury and reduce flowering on *A. houstonianum* (Hatterman-Valenti and Mayland, 2005). Chemical control is not advised when this plant is growing in agricultural fields, hence 20% salt solution is suggested in this situation (BioNet-EAFRINET, 2016).

Alternanthera philoxeroides (Mart.) Griseb. (Family: Amaranthaceae)

Other Scientific Names: *Bucholzia philoxeroides* Mart.

Vernacular names: Bengali- Danta; Kannada- Dodda honagone, Mosale honagone

Common name: Alligator weed, Pig weed and Phackchet

Alternanthera philoxeroides is an notorius weeds in the world because it invades both terrestrial and aquatic habitats. In terrestrial habitat the plant forms dense mats with a massive underground rhizomatous root system (ISSG, 2017). In aquatic habitat it has the potential to become a serious threat to rivers, waterways, wetlands and irrigation systems.

- Distribution: *Alternanthera philoxeroides* is native to South America, principally the Parana River region (Julien *et al.*, 1995), From Guyana to Brazil and Northern Argentina (USDA-ARS, 2016). It was introduced into Europe, North and Central America, the Caribbean, tropical Asia and Oceania (ISSG, 2016).
- Description: It is decumbent or ascending glabrate aquatic perennial with often fistulose stems. Inflorescence of the plant is mostly terminal and occasionally axillary white glomes. Fruit an indehiscent reniform utricle (Flora of Panama, 2016).
- Management: Currently, *A. philoxeroides* is listed as invasive in the United States, Puerto Rico, France, Italy, India, Sri Lanka, China, Taiwan, Indonesia, Myanmar, Singapore, Australia and New Zealand (Weber *et al.*, 2003). Optimum growth of this species occurs in fresh water with a high nutrient level. It can tolerate brackish water and,

once established on land, will survive extreme dry periods (DAF, 2016). Considering its vigorous growth and ability to re-establish from stem fragments, alligator weed has the potential to hamper native biodiversity widely. Therefore effective management strategies should be adopted to control its invasion. Control measures for this species are given below;

- Mechanical control: Successful mechanical/physical removal of this plant is extremely difficult since the plant is able to re-establish from very small pieces (DiTomaso *et al.*, 2013). So, mechanical harvesting and ploughing are not suitable control methods for *A. philoxeroides* (Julien and Broadbent, 1980).
- Chemical control: Eradication of this weed in rice fields with herbicides including bentazone, bifenox, dicamba, fenoprop, pendimethalin, propanil and triclopyr, without causing serious damage to the crop; 2, 4-D has shown only a temporary effect (Parsons and Cuthbertson 1992). Application of dichlobenil followed 9 months later by metsulfuron; and three sprays over 18 months with metsulfuron or a metsulfuron/glyphosate mixture also has shown effective results (Bowmer, 1992).
- Biological Control: Successful biological controls reported in the USA, Australia, New Zealand, China and Thailand (Hayes *et al.*, 2013). *Agasicles hygrophila* from Argentina has been introduced into other countries. In Australia, it is established and successfully controls *A. philoxeroides* in aquatic habitats. In New Zealand, it destroys most foliage of the weed annually. In Thailand, it has spread around Bangkok and the lower central plain area producing excellent control of *A. philoxeroides*. In the USA, this biocontrol agent is generally successful in controlling the weed in Florida, Louisiana and Texas; it is also well established in South Carolina, Georgia, Alabama and Mississippi (Julien, 1992). The pathogenicity of fungal agents against *A. philoxeroides*, including *Alternaria alternata* has been investigated in China (Zhou *et al.*, 2016).

Chromolaena odorata (L.) R.M. King & H. Rob. (Family: Asteraceae)

Other Scientific Names: *Eupatorium conyzoides* Vahl, *Eupatorium odoratum L., Osmia odorata* (L.) Schultz-Bip.

Vernacular names: Assamese-Jarmoni-bon, Koli bon, Nogor bera; Hindi- Tivra Gandha, Bagh Dhoka

Common name: Siam weed

Chromolaena odorata (L.) R.M. King & H. Rob. *(Photo credit: Dr. A. Rajasekaran, IFGTB)*

- Distribution: *Chromolaena odorata* is native of tropical Central and South America, Mexico and the Caribbean; however, the exact northern and southern limits of its native range remain uncertain and likely to also include some regions outside of the tropics (USDA-ARS, 2007).
- Description: *Chromolaena odorata* is a scrambling perennial shrub that originated in the Americas, but is now common in sub-Saharan Africa, Asia and Oceania, where it has become a serious weed (Omokhua *et al.*, 2016).
- Management: *C. odorata* is considered as a very serious weed in all types of perennial crops in the humid areas of the Palaeotropics. In low-growing plantations such as coffee and cocoa, this weed completely smother the crop, whereas taller plantation doesn't get this problem due to closed canopy. Considering the threats to biodiversity, control measures for this species are given below in brief;
- Mechanical control: *C. odorata* has strong coppicing potential from roots so slashing the stems manually or mechanically is not advisable. The root must be dug out either manually in moist soil or with the help of equipments at least twice during the growing season (Muniappan and Marutani, 1991). Seedlings and young plants can be removed by hand-pulling with a follow-up clearance every 2-3 months is necessary (Zachariades and Goodall, 2002). Cultural practices involving growing of other competitive species as ground-cover crops can control *C. odorata* in the first years in perennial plantations (Muniappan and Marutani, 1991).
- Chemical control: For control of *C. odorata* germination, pre-emergence herbicides such as diuron or metribuzin may be used. Best control of *C. odorata* is usually obtained when herbicides are applied to young shoots after slashing. The following may be used as post-emergence treatments:
  - 2, 4-D; glyphosate; asulam; paraquat; triclopyr; imazapyr; metsulfuron; tebuthiuron; atrazine (which also inhibits germination);
  - Picloram and classical combinations such as picloram + 2, 4-D; dicamba + 2, 4-D. 2, 4-D, atrazine and paraquat are only effective on seedlings or young plants.

  For mature plants, glyphosate or combinations including picloram, dicamba or triclopyr will be needed, and even then, repeat treatments are likely to be necessary (CABI, (2019). Herbicides picloram + triclopyr or fluoxypyr in combination with a wetting agent is followed in Australia (Waterhouse and Zeimer, 2002).
- Biological control: Various biological agents were used for control of *C. odorata* with limited success. *Pareuchaetes pseudoinsulata* was released in West Africa, South and South-East Asia and the Pacific. However, predation of the larvae resulted in poor establishment. Similarly introductions of the inflorescence-feeding weevil, *Apion brunneonigrum*, in West Africa and in Asia were impeded by the need to send field-collected adults because no successful mass-breeding technique had been developed. The introductions of the stem gall fly, *Cecidochares connexa (Procecidochares connexa)* during 1993 in most Indonesian islands under a regional co-operative programme in South-East Asia resulted in good control of the plant (Chiu *et al.*, 2005).

Eichhornia crassipes (Mart.) Solms (Family: Pontederiaceae)

Other Scientific Names:	*Eichhornia cordifolia* Gandoger, *Eichhornia crassicaulis* Schlect.
Vernacular names:	Assamese- Pani-meteka, Meteka, Jarmoni-pena, Kachuri-pana; Malayalam- Kakapola, Kulavazha
Common name:	Water hyacinth, Akasa thamarai, German pana, Jalkhumbi, Kachuripana, Kajor pati, Kolavazha, Kulavali.

Eichhornia crassipes (Mart.) Solms is a major freshwater weed in most of the frost-free regions of the world and is generally regarded as the most troublesome aquatic plant (Holm *et al.*, 1977).

Eichhornia crassipes (Mart.) Solms *(Photo credit: Dr. A. Rajasekaran, IFGTB)*

- Distribution: Water hyacinth, *Eichhornia crassipes* (Mart.) Solms of family Pontederiaceae is a native of South America, is one of the worst aquatic weeds in the world. It is introduced into India in 1896 as an ornamental plant at botanical garden at Bengal (Biswas and Calder, 1954). In India, it is found in Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Delhi, Goa, Gujarat, Haryana, Himachal Pradesh, Punjab, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Nagaland, Odisha, Rajasthan, Tamil Nadu, Tripura, Uttar Pradesh and West Bengal (Gopal, 1987).

- Description: It is an aquatic plant which can live and reproduce floating freely on the surface of fresh waters or can be anchored in mud making it the most successful colonizer in the plant world (Wolverton and McDonald, 1979). The initial leaves of seedling are elongated and strap-like, but soon develop the familiar spathulate form and, swollen petioles which ensure that, once dislodged, the seedlings will float from the mud into open water. The plant is very variable in size. Leaves consist of petiole (often swollen, 2-5 cm thick) and blade (roughly round, ovoid or kidney-shaped, up to 15 cm across). The base of the petiole and any subsequent leaf is enclosed in a stipule up to 6 cm long. Roots develop at the base of each leaf and form a dense mass. The inflorescence is a spike, each spike, up to 50 cm high, is subtended at the base by two bracts and has 8-15 sessile flowers (rarely 4-35). The flowers are tristylous. They have six stamens and one style (CABI, 2019).

- Management: The species has invaded almost all water bodies of the country. Most of the Country's Ramsar sites have been affected by the species (Narayanan *et al.*, 2007). Hence appropriate management plan should be implemented effectively to control its rapid invasion. Some control methods are discussed below in brief;

- Mechanical control: Physical removal or destruction of the infestation may be achieved on a small scale by manual removal. On the larger scale, machinery is needed, either shore-based, or mounted on boats. Manual removal of water hyacinth using mechanical mowers, dredgers or manual extraction methods is probably the most widely practiced method of control in developing countries like India (Tacio, 2009).

- Chemical control: 2, 4-D and Glyphosate have been widely used for control of *E. crassipes*. Glyphosate is much more expensive than 2, 4-D but has possible advantages over 2, 4-D in not causing taint of drinking water and in causing a slower kill of the weed (Findlay and Jones, 1996).

- Biological control: Biological control of the species started with the introduction of the Eichhornia Weevils (*Neochetina* Spp) in the late 1990s. The exotic water hyacinth weevils *Neochetina eichhorniae* are reported to be most effective bio-control agent (Yasotha and Lekeshmanaswamy, 2012). The efficacy of grass carp *Ctenopharyngodon idella* (Cyprinidae) and weevils *Neochetina* spp. (Curculionidae) to control water hyacinth was investigated using a square net cage (happas) in Cuddalore district, South India. This novel combination of insects and fish is found to be superior to individual treatments for controlling the weed growth within 110 days (Gopalakrishnan *et al.*, 2011). *Alternaria eichhorniae* also have been reported to be a potential bio-control agent. Dried leaf powder of *Plectranthus amboinicus* (Lour.) Spreng, an Indian medicinal herb shows remarkable allelopathic inhibition when absorbed through roots of water hyacinth (Kathiresan, 2000).

Lantana camara L. (Family: Verbenaceae)

Other Scientific Names:	*Camara vulgaris, Lantana scabrida*
Vernacular names:	Hindi- Ghaneri, Chadurana, Choti podari; Tamil- Arippu, Arisimalar; Kannada- naathada hoo, puchuli, ari hoo, chandranga
Common name:	Sleeper weed, lantana, wild sage

Lantana camara is a highly variable species which has been widely cultivated for over 300 years. Hundreds of cultivars and hybrids exist (Howard, 1969) and most of them belong to the *L. camara* complex (Stirton, 1979). Cultivars can be distinguished morphologically (flower size, shape and colour; leaf size, hairiness and colour; stem thorniness; height and branch architecture), physiologically (growth rates, toxicity to livestock) and by their chromosome number and DNA content (Stirton, 1979; Gujral and Vasudevan, 1983; Scott *et al.*, 1997).

Lantana camara is considered a problem weed in many parts of India in which it has been introduced (Iyengar, 1933). Due to its prolific nature of flowering and dispersal, the species tends to alter the structure of the terrestrial ecosystem by gregarious presence. The species forms dense thickets and tends to eliminate the native species. There are some important earlier studies in India that look at *L. camara* for its ability to invade, despite it widespread distribution (Mohan Ram and Mathur 1984; Mathur and Mohan Ram 1986; Bambaradeniya *et al.,* 2002; Napompeth *et al.,* 2003; Sahu *et al.*, 2008; Raghubanshi and Tripathi 2009).

Lantana camara L. *(Photo credit: Dr. A. Rajasekaran, IFGTB)*

- Distribution: Native to West Indies (Sellers and Ferrell, 2010), this species is naturalized in approximately 60 countries or island groups between 35^0 N and 35^0 S latitudes. Occurs widely in the Asia-Pacific region, Australia, New Zealand, Central and South America, West Indies and Africa. The plant is still widening its range (Bhagwat *et al.*, 2012).
- Description: Lantana is a perennial, erect or prostrate shrub with small, multicolored flowers. Typically the more mature flowers are darker in color (lavender and red). Fruit of lantana is tiny (0.2 inches in diameter) and round. Initially green, the seeds will change to a deep purple and eventually black color (Sellers and Ferrell, 2010).
- Management: Once introduced as ornamental plant worldwide, Lantana has became most annoying weed now. Therefore an integrated approach should be adopted to control and manage invasion of this species. These include manual removal, burning, chemical control, shading, and prevention.
- Mechanical control: These control measure includes manual pulling, uprooting, fire, stick racking, slashing and cutting. Along with these mechanical methods, use of chemicals to prevent further growth is preferable to prevent further infestation. Suggested control measures are;
  - Hand cutting using brush cutters, hand pulling, chain pulling and flame weeding
  - Fire is often used prior to mechanical or herbicidal control to improve their effectiveness
  - Fire can provide some control when used under the controlled conditions, especially if the fires are hot and the Lantana is actively growing.
- Chemical control: During the active growing period, use of fluroxypyr @ 0.5 to 1 liter / 100 l water, glyphosate @ 1l / 100 l water, triclopyr @ 1l / 60 l of water and Grazon DS (300 g/l triclopyr + 100 g/l picloram) @ of 350 ml/100 l water per ha is recommended. Post emergence application of glyphosate (2 kg ha-1) may provide good control. Applications are to be done when there is good soil moisture and during the active growing period, either in the morning or late in the afternoon (FAO, 2010).
- Cut Root Stock Method: Methods like cutting, slashing and burning only remove above plant portion and the plant stays alive below the soil. In fact, when such methods are used, the Lantana produces multiple shoots from the transition zone that lies 2-3 inches below the soil (Babu *et al.* 2009; Love *et al.* 2009). Recurring slashing and cutting makes the roots of the plant grow bigger in size and the plant further grows profusely. Hence it is important to find a effective management practices to control Lantana invasion as long as its huge potential of expansion is concerned.

  Babu *et al.* (2009) and Love *et al.* (2009) reported a successful new Lantana removal technique, the cut-rootstock method. Cut root stock method is gaining significant attention nowadays, as it has proven its visible superiority over existing methods of Lantana eradication. The Cut Root-Stock method involves cutting the root exactly below the transition zone and thus eliminates the reproductive ability of the plant. This method involves making a small cut below the soil level, with minimum disturbance of the soil. The scar left at the point of removal is 9-12 inches in diameter. Therefore there is very little disturbance of dormant Lantana seeds lying in the soil. Because of the minimum disturbance of the soil other species of plants lying under the Lantana bush including grass species are left unaffected, helping their quicker regeneration. Methods like burning and mechanical removal involve large scale destruction of other plant species in the project areas. The Cut Root-Stock method involves 50-60% less manual effort compared to cutting or slashing. This was observed during the field demonstrations where the teams with no prior experience were able remove several large bushes in a short span of 20-30 minutes.

  Successful restoration of Lantana invaded areas using this Cut Root Stock method has been reported in many parts of the country including Corbett National Park, Rajaji National Park and other forest areas.

- Biological Control: Various agents are being examined to eradicate Lantana by biological means. Of the 16 insect herbivore species imported into South Africa for biological control of *L. camara,* six have become established and two were already present. Two leaf-feeding chrysomelid beetle species, *Octotoma scabripennis* Guèrin-Mèneville and *Uroplata girardi* Pic, usually in association with the tingid bug, *Teleonemia scrupulosa* Stål, are exerting some degree of control. A seed-feeding agromyzid fly, *Ophiomyia lantanae* (Froggatt), may be contributing to the overall stress on the plant, but its contribution as biocontrol has not been determined (Cilliers and Neser, 1991).

  Biological organisms tested for controlling *L. camara* have failed as it has several varieties or forms resulting in complicating the introduction and establishment of exotic insects (Priyanka *et al.*, 2013). In India attempts were made by Forest Research Institute, Dehradun to identify insects that feed on Lantana (Beeson and Chatterjee, 1939). Lantana is also known to be controlled by *Teleonemia scurpulosa* which is commonly popular as Lantana lace bug (Sharma, 1988).

  Worldwide, well over 200 releases of biocontrol agents have been made (39 different natural enemies have been released in 29 countries), however, in the majority of cases the control agent either failed to become established or became established without achieving control. Despite this limited success, classical biological control is still considered to be the only viable, long-term control option, since it offers a safe, economic and environmentally benign method of suppressing the weed (CABI, 2019). The most widely established species include *Ophiomyia lantanae, Uroplata girardi* and *Octoma scabripennis.* Day *et al.* (2003) have produced a detailed review of 48 of these control agents.

Mikania micrantha Kunth (Family: Asteraceae)

Other Scientific Names: Eupatorium denticulatum Vahl, Eupatorium orinocense (Kunth) Gómez de la Maza, Eupatorium orinocense (Kunth) M.Gómez

Vernacular names: Malayam- Vayara; Manipuri- Oori Hingchabi

Common name: Bitter vine, Japani habi

Mikania micrantha Kunth *(Photo credit: Dr. A.Rajasekaran, IFGTB)*

- Distribution: *Mikania micrantha* is a fast growing vine, native to Central and South America. It was intentionally introduced into a number of countries and has since become a major weed in Southeast Asia and the Pacific and is still extending its range (CABI, 2019).

- Description: *Mikania micrantha* is a perennial twining herb with a wide altitudinal distribution, as it may grow at an elevation of 2000 m or more. Similarly *M. micrantha* can grow in a range of soil types, from acidic to alkaline (pH 4.1 - 8.3) and from infertile to highly fertile (organic material 2.29 - 32.85) (CABI, 2019). *M. micrantha* grows luxuriantly on leached and nutrient poor sandy loam to clayey soils. Heavy grazing and browsing promotes the spread of Mikania into new ecosystems. The weed cannot tolerate shade and hence fails to penetrate undisturbed natural forest areas (http://www.fao.org).

- Management: *M. micrantha* is a serious weed of agriculture, affecting over 20 species including plantation trees such as species of Citrus, Cocoa, Coffee, Tea, African oil palm, Coconut etc. Several methods have been adopted for the management of invasion of *M. micrantha* including mechanical, chemical and biological control from time to time (Sankaran *et al.*, 2008; Sankaran and Pandalai, 2004). Some methods are given below;

- Mechanical control: Traditionally, manual control of newly infested crop areas have been carried out by rolling, drying and burning the plants but this proved to be unsustainable (Ismail, 2001). In India manual methods (sickle weeding or uprooting) have been used but these are more expensive than chemical options (Sankaran, 1999).

When the vines of M. micrantha are cut near to the ground once a month for three consecutive months in summer and autumn and then in winter and spring, 90% of the plants can be eliminated (Yau-Lun Kuo et al., 2002). Hand-pulling in southern China is most effective before the end of October, i.e. prior to seed maturity, or during the March rainy season. A hand-pulling campaign by thousands of citizens was initiated by the Shenzhen government (Guangdong Province) in 2000 and proved quite effective, as many dying trees damaged by *M. micrantha* subsequently recovered (Zhang *et al.*, 2004).

Regeneration of *M. micrantha* from the clumps of previous growth left in soil, was reduced in the post burn phase in fallows subjected to flaming (Swamy and Ramakrishnan (1987). Though various methods including chemical, cultural, mechanical and biological have been attempted in India, currently mechanical removal is widely practiced.

- Chemical control: Young *M. micrantha* is susceptible to standard post-emergence herbicides such as 2, 4-D, paraquat and glyphosate. In Malaysia applying paraquat and/or 2, 4-D amine was the preferred method of control (Ahmad-Faiz, 1992). A mixture of glyphosate and dicamba resulted in a 90% weed control by 30 days after application and 40% by 120 days. In Indonesia herbicides application of 2, 4-D amine, 2, 4-D - sodium and ioxynil, applied six weeks apart, hexazinone + diuron at four weeks apart and 2, 4-D - sodium followed six weeks later by glyphosate showed good control of Mikania (Mangoensoekarjo, 1978).

- Biological control: Biocontrol attempts using insects are not successful due to various reasons. However, a highly damaging rust species *Puccinia spegazzinii*, isolated from Trinidad has been identified as a potential candidate for biocontrol of Mikania in India. *P. spegazzinii* was released in Assam during October 2005 and March 2006 and in Kerala during August 2006 however, it failed to establish at any site (Ellison and Day, 2011; Kumar *et al.*, 2016).

Zhang *et al.*, (2004) suggested that the establishment of a herb layer in managed orchards, forests, perennial crops (tea and tree plantations), parks and on newly developed areas should somewhat hinder *M. micrantha* seed germination and by increasing understorey shade in forests it should make growing conditions unsuitable for the vine (Zhang *et al.*, 2004). *M. micrantha* can be controlled by tea mosquito bug known as Helopeltis theivora (Abraham *et al.*, 2002).

Mimosa diplotricha C. Wright (Family: Fabaceae, Subfamily: Mimosoideae)

Other Scientific Names: Mimosa invisa C. Mart.Morongia pilosa Standley, Schrankia brachycarpa Benth. Schrankia pilosa (Standley) Macbr.

Vernacular names: Anathottavadi

Common name: Creeping sensitive plant

M. diplotricha (syn. M. invisa) is a small, often scrambling, neotropical shrub that has invaded many countries in the old tropics and many oceanic islands. It forms impenetrable spiny thickets that invade highly disturbed sites, but agricultural systems in particular (CABI, 2019).

Mimosa diplotricha C. Wright *(Photo credit: Dr. Dhruba J. Das, RFRI, Jorhat)*

- Distribution: *M. diplotricha* is native to the neotropics, including much of South and Central America, as well as the Caribbean (Holm *et al.*, 1977). It has now become widespread throughout the wet tropics and subtropics, and is usually a very invasive species wherever introduced (CABI, 2019). In India, it is reported in Karnataka, Kerala, Assam and Uttar Pradesh (Sannamarappa, 1987; Thomas and George, 1990; Sannamarappa, 1987; Alex *et al.*, 1991; Rai and Kanodia, 1980)
- Description: *M. diplotricha* is a scrambling, strongly branched shrub growing 1-2 m tall, woody at the base with age, with stems stretching to about 6 m long, forming low, tangled masses or climbing on other vegetation with the aid of its spiny stems. The green or purplish tinged stems are 4- or 5-angled in cross-section and covered with abundant sharp, recurved, yellowish spines, 3-6 mm long, on the angles and fine, white hairs. The scattered bright-green leaves are finely bipinnate and 10-20 cm long. The leaves consist of 4-9 pairs of pinnae, 3-6 cm long, each with 12-30 pairs of opposite, sessile, lanceolate, acute leaflets, 6-12 mm long and 1.5 mm wide. The leaflet pairs fold together when touched and at nightfall, but they are considered as only moderately sensitive. The rachis is thickened at the base with slender, tapering stipules, and finely hairy with a few prickles along the back. The flowers are pinkish-violet in colour and occur in globose heads about 12 mm in diameter, singly, in pairs or threes on individual stalks originating in the axils of young leaves. The plant reproduces only by seed (Holm *et al.* 1977; Henty and Pritchard 1975).

- Mechanical control: Cultivation, cutting or burning are not generally effective methods of control because plants vigorously regrow from the root crown, and seedling development is rapid and prolific (Waterhouse and Norris, 1987; Parsons and Cuthbertson, 1992). The plant produces copious quantities of seeds which retain their viability in the soil for long periods (Muniappan and Viraktamath, 1993).
- Chemical control: *M. diplotricha* has been successfully controlled in many situations using foliar applications of herbicides such as picloram, clopyralid and fluroxypyr (Parsons and Cuthbertson, 1992).
- Biological Control: *Heteropsylla spinulosa* from Brazil is well established and caused a dramatic reduction in vigour and seed production of *M. diplotricha* in Australia (Parsons and Cuthbertson, 1992).

The best approach to control the weed is usually to combine different methods. Control may include chemical, mechanical, fire and biological methods combined with land management changes and will be site specific. Early infestations should be treated with herbicide or slashed before seeding occurs; once a plant seeds, infestations will re-occur each year for many years as seeds retain their viability (DAF, 2016).

Parthenium hysterophorus L. (Family: Asteraceae)

Other Scientific Names:	*Parthenium hysterophorus* var. *lyratum* A.Gray
Vernacular names:	Hindi- Congress grass, Congress-ghas, Gajar ghas, Jhilmil; Kannada- congress gida, congress hullu, congress kale; Telugu- Congresspoolu, Pitchi genjayi, Pitchi maachi pathre
Common name:	Carrot grass, Congress grass and Gajar Ghans

- Distribution: *Parthenium hysterophorus* L. (Asteraceae), a noxious plant, inhabits many parts of the world, in addition to its native range in North and South America and the West Indies (Picman and Picman, 1984). In India, it is distributed in Assam, Bihar, Chandigarh, Delhi, Gujarat, Haryana, Himachal Pradesh, Indian Punjab, Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal (CABI, 2019).
- Description: *Parthenium hysterophorus* is an erect, branched, aromatic, annual herbaceous plant with a deep taproot. Both leaves and stems are covered with short, soft trichomes. The species reproduces by seed and has vigorous growth. The large lower leaves are spread on the ground like a carpet, without allowing any vegetation underneath it (Lakshmi and Srinivas, 2007). Flower heads are both terminal and axillary, pedunculate and slightly hairy, being composed of many florets formed into small white capitula, 3-5 mm in diameter. Each head consists of five fertile ray florets (sometimes six, seven or eight) and about 40 male disc florets. Seeds (achenes) are black, flattened, about 2 mm long, each with two thin, straw-coloured, spathulate appendages (sterile florets) at the apex which act as air sacs and aid dispersal (CABI, 2019).
- Management: Since, this weed has become huge menace for biodiversity of India, efforts were made to manage the weed by efficient practices and control measures. However, so far cost effective and reliable methods are not available. Therefore, there is a need to adopt an integrated Parthenium management strategy by amalgamating all existing methods combined is need of hour. Some control measures are discussed below;
- Mechanical control: Manual uprooting of Parthenium before flowering and seed setting is the most effective method to control its invasion. Uprooting the weed after seed setting will increase the area of infestation. Some landholders have achieved success in ploughing the Parthenium weed in the rosette stage before it seeds, but this must be followed up by sowing a crop or direct seeding the perennial pasture (Kaur *et al.*, 2014). Physical

control involves hand weeding, a time consuming and unpleasant job, made worse by the health hazards involved with handling Parthenium weed.

Burning also employed to manage this weed, but not a useful control strategy. However, research suggests that burning for other purposes (e.g., woody weed control) will not result in an increased infestation of parthenium as long as the pasture is allowed to recover before stock is introduced. This too has proved to be inadequate due to two reasons; it requires large quantity of fuel and burning destroys all other economically important plants growing in its vicinity (Ray and Gour, 2012).

- Chemical control: Chemical control is an effective method to control parthenium in the areas where its natural enemies are absent. Use of chemical herbicides, such as chlorimuron ethyl, glyphosate, atrazine, ametryn, bromoxynil, and metsulfuron, are known to be very effective in controlling this weed (Kaur *et al.*, 2014). Application of 2,4-D EE (0.2%) and metribuzin (0.25 and 0.50%) were found more effective for controlling parthenium at 15 days after spraying (DAS), causing complete kill of parthenium population, and did not allow any emergence of weed (Javaid, 2007; Gaikwad *et al.*, 2008).

The stage/time of parthenium weed for herbicidal control is important and the weed was effectively controlled at rosette stage in wasteland, non cropped areas, along railway tracks, water channels, and roadsides (Khan *et al.* 2012). The most effective treatments for parthenium weed control were glyphosate and metribuzin, having higher mortality at 4 weeks after treatment (WAT) at both rosette and bolted stages than 2, 4-D, triasulfuron + terbutryn, bromoxynil + MCPA and atrazine + s-metolachlor, atrazine, s-metolachlor. Pendimethalin was the least effective treatment for both growth stages. Overall, the efficacy of herbicides was promising on rosette parthenium plants than bolted plants. In open wasteland, non cropped areas and along railway tracks and roadsides, the spraying of a solution of common salt (Sodium chloride) at 15–20% concentration has been found to be effective (Kaur *et al.*, 2014).

- Biological Control: Biological control by using *Zygogramma bicolarata* a Mexican beetle has proven its reliability. Large patches of land heavily infested with this weed have been cleared off by the beetle in several parts of India (Sushilkumar, 2005). Few plants of Parthenium in advanced stages of wilting, found to be infected with the root rot fungus, *Rhizoctonia solani*. A survey conducted in Coimbatore district of Tamil Nadu revealed that *Lasiodiplodia theobromae* cause blight and damage to Parthenium in 15 - 30 days growth stage. Also, *Oidium partheni* cause severe damage to Parthenium at flowering stage (Jeyalakshmi *et al.*, 2005).

Joshi, (1991) reported that *Cassia sericea* has a good antagonistic effect against Parthenium and can replace it from the invaded areas. However its success was reported to be limited only from Karnataka. According to Singh *et al.*, (2005), Eucalypt oils have a potential for suppressing the emergence, growth and biomass accumulation in *Parthenium*. On the other hand Batish *et al.*, (2004) pointed that in order to control Parthenium on long-term based community participation is crucial in addition to the integrated use of other methods.

Prosopis juliflora (Sw.) DC. (Family: Fabaceae; Subfamily: Mimosoideae)

Other Scientific Names:	*Acacia cumanensis* Willd., *Acacia juliflora* (Sw.) Willd., *Acacia salinarum* (Vahl) DC., *Algarobia juliflora* (Sw.) Heynh.
Vernacular names:	Hindi- Kabuli kikkar, Vilayati babul, Vilayati khejra, Vilayati kikkar; Tamil- Cimaikkaruvel, Velikattan; Telugu- Circar kampa, Circar mullu
Common name:	Vilayati babool, Vilayati babul, Vilayati khejra, Vilayati kikar

- Distribution: *P. juliflora* is native to Mexico, Central and northern South America. *P. juliflora* is probably present in at least some frost-free arid or semi-arid regions of every country in Africa, and is possibly present but localized in many more Asian countries (CABI, 2019). In India, it is distributed in Andhra Pradesh, Assam, Bihar, Chandigarh, Dadra and Nagar Haveli, Daman, Delhi, Diu, Goa, Gujarat, Haryana, Indian Punjab, Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal (Burkart, 1976, CABI, 2019)..

- Description: *P. juliflora* is a tree 3-12 m tall, sometimes shrubby with spreading branches; wood hard; branches cylindrical, green, more or less round- or flat-topped, somewhat spiny with persistent, green (foliage, glabrous or somewhat pubescent or ciliate on the leaflets; spines axillary, uninodal, divergent, paired, or solitary. Leaves bipinnate, glabrous or pubescent, 1-3 pairs of pinnae, pinnae 3-11 cm long; leaflets 6 to 29, generally 11 to 15 pairs per pinna, elliptic-oblong, glabrous or ciliate. Racemes cylindric, 7-15 cm long, rachis puberulent; florets as usual, greenish-white. Legume straight with incurved apex, straw-yellow to brown, compressed, linear with parallel margins, stalked and acuminate, 8-29 cm long x 9-17 mm broad x 4-8 mm thick; stipe to 2 cm; endocarp segments up to 25, rectangular to subquadrate, mostly broader than long; seeds oval, brown, transverse (Burkart, 1976, CABI, 2019).

- Management: *Prosopis juliflora* has been included in the Global Invasive Species Database (GISD 2010). This species can be very aggressive invader and has tremendous potential to hamper growth of native vegetation significantly. Some methods of an integrated management approach are given below.

- Mechanical control: Mechanical control options include the physical felling or uprooting of plants along with burning (Van wilgen et al., 2001). Controlling alien plant invasions manually may include hand-pulling, uprooting, hoeing, felling or cutting back. Such methods can be labour intensive, but in regions where manual labour is readily available and can be hired cheaply manual control is often both effective and economical. Ring-debarking (girdling) may also be effective, albeit only for eliminating woody invaders of species that do not coppice (Abdulahi *et al.*, 2017).

- Chemical control: Chemical control methods, includes use of approved herbicides to increase effectiveness of manual and mechanical control methods. Applying systemic herbicides to cut tree-stumps or to incisions made in the bark of trees or shrubs (i.e. frilling) will, on spreading through the vascular tissue of treated invaders, eventually kill the targeted trees or shrubs. Basal stem applications and stem injections have the same effect (Abdulahi *et al.*, 2017). These applications are very target specific with no discernible non target impacts (Gordon and Arne, 2013). Larger trees and shrubs are usually killed by cutting the stem at ground level and applying the suitable herbicide on cut stem portion. Herbicides like Round up, 2-4, D, Glenside Kerosene and diesel oil are used. Foliar sprays of herbicides such as glyphosate are widely used to control the seedlings of woody invaders. Herbicidal sprays, applied using portable 'pack' sprayers, offer a fast and effective means of control, yielding rapid results. Where chemical treatments can be administered typically to individual plants, the risks of inflicting collateral damage, detrimental impacts on non-target species, always a danger with herbicides can be minimized (Abdulahi *et al.*, 2017).

Panchal and Shetty, (1977) reported that ammonium sulfamate was successful in killing *P. juliflora* trees and as a stump treatment. Recently Shanwad *et al.*, (2015) reported that double applications of herbicides like Glyphosate and 2, 4-D ester seems to be better options than the other chemicals and the single application for the control of Prosopis juliflora.

- Biological Control: Several biological control programmes using species of seed-feeding bruchid beetles, twig girdlers and psyllids have been developed and implemented. The twig girdler (*Oncideres limpida*) attacks *P. pallida* in Brazil (Lima, 1994), whereas *Oncideres rhodostricta* is seen as a serious pest of *P. glandulosa* in the

USA (Polk and Ueckert, 1973). Psyllids are known to severely affect the growth of Prosopis (Hodkinson, 1991) and have been suggested for use in controlling invasions.

The seed-feeding insects (*Mimosetes protractus* and *Neltumius arizonensis*) were introduced to eastern South Africa in conjunction with the bruchid beetles *Algarobius prosopis* and *A. bottimeri* for the control of invasive *Prosopis* species. *N. arizonensis* and *A. prosopis* were successful in establishing themselves in large numbers and having a significant effect on *Prosopis* spp., whereas the other species were only found in low numbers (Hoffmann *et al.*, 1993). Maximum damage to seed occurred where grazing was controlled, as the multiplication and progress is hampered by livestock devouring pods before the insects destroy them. The mirid *Rhinocloa* sp. causes widespread damage and is thought to lead to substantial mortality of trees (Fowler, 1998). Insect species continue to be tested for their efficacy and host specificity as possible biological control agents of Prosopis species in Australia (Klinken *et al.*, 2009).

- Integrated control: Fire has been used in conjunction with other methods in the development of integrated eradication programmes. For example, spraying with herbicides produces dead wood that will ignite and support a sustained fire with more likelihood of killing the remaining trees (CABI, 2019). Weedy invasions of Prosopis can be successfully adapted to agroforestry systems by thinning and pruning (Felker *et al.*, (1999). This method was adapted by Tewari *et al.*, (2000) and Pasiecznik *et al.*, (2001).

Restoration of Invaded Habitats

The Society for Ecological Restoration International (SERI) defines ecological restoration as the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed. Developing restoration models for invaded landscapes can play a crucial role in controlling the invasive plants and restoring the native vegetation. Restoration of a site occupied by an invasive species can cause unique challenges because some species can continue to affect ecosystem after their removal, preventing attainment of the desired restoration outcome (Cronk and Fuller 1995). After removal or eradication of IAPS, subsequent restoration along with effective land use is necessary but is often ignored. Restoration of sites degraded by IAPS and soil erosion pose challenges. After invasion the geography may no longer look like the pre-invasion conditions, and removal of the IAPS may cause further erosion, especially if there is a lag between removal and native plant establishment. Highly degraded sites may no longer be able to support the desired native species assemblages.

Under these circumstances it may be necessary to take a phased approach and stabilize the soil using synthetic or biodegradable materials or establish native vegetation before invasive plant removal (D'Antonio and Meyerson, 2002). In some degraded sites it may be necessary to introduce suitable native plant species to assist with the restoration process. Although it is common to use invasive plants during the re-vegetation of degraded lands, Ewel *et al.*, (1999) argued that the growth potential of native species has not been fully explored enough in many such situations and research is needed in this area.

Removal of invasive species does not always guarantee the restoration of native biological diversity (D'Antonio and Meyerson, 2002). However in some cases removal has led to an increase in native species diversity, e.g., *Mimosa pigra* management with a combination of herbicide, mechanical methods, fire, and biological control (Paynter and Flanagan, 2004), in other cases removal has resulted in decrease in native species diversity, e.g., the post-fire use of herbicides in the control of *Asparagus asparagoides* (Turner and Virtue, 2009). In India, Ekta, (2014) reported that *P. juliflora* reduced the growth of other native trees significantly in the Delhi ridge forest of semi-arid region. However Naudiyal *et al.*, (2017) doubts the general perception regarding *P. juliflora's* negative impact on biodiversity according to their study they found that factors like anthropogenic disturbances and grazing are causing significant negative impact on the vegetation diversity, rather than *P. juliflora* itself. Also, it is reported that *P. juliflora* can help in the site restoration efforts (Pandey *et al.* 2015). McNeish *et al.* (2017) showed that removal of invasive species growing alongside a stream or river can also improve the biodiversity of aquatic organisms. It is thus important to understand the site-specific response of native communities to different invasive species removal or control techniques (Flory and Clay, 2009).

In India, Babu *et al.*, (2009) successfully eradicated and restored two Lantana-invaded sites in Corbett Tiger Reserve, India. Hiremath *et al.*, (2018) tested the effectiveness of two Lantana removal techniques (cutting and burning, and uprooting) to restore *Lantana camara* invaded Tropical deciduous forest and concluded that no Lantana removal is likely to be effective without post-removal monitoring and weeding and also recommended post-removal planting of species that can pre-empt Lantana re-colonization, and respond positively to disturbances like fire and grazing, which are known to encourage Lantana's spread. More efforts on restoration of invaded landscapes for mitigating negative impacts of other invasive species need to be considered for implementation in India.

Understanding soil seed bank provides knowledge on suitability of restoration techniques in the invaded habitat. From a restoration perspective, determining the contribution of an invasive species' propagules to the seed bank can help assess the local persistence of the species (Gioria *et al.* 2014), while quantifying the abundance and composition of indigenous species within the seed bank provides an indication of the potential for the original (i.e. pre-invasion) species to re-establish. Soil seed bank characteristics can constrain the suitability of restoration techniques therefore understanding the impact of habitat degradation on the soil seed bank is important from a conservation perspective.

Assisted Natural Regeneration (ANR): It is a simple, low-cost forest restoration method which aims to accelerate, rather than replace, natural successional processes by removing or reducing barriers to natural forest regeneration such as soil degradation, competition with weedy species, and recurring disturbances (e.g., fire, grazing, and wood harvesting). Variety of technical methods is used in applying ANR, and the following basic steps can be modified according to site conditions, restoration objectives, and resource availability. Steps involved in ANR implementation include; marking of woody regeneration, liberation and tending of woody regeneration, suppressing weedy vegetation, protection from disturbance and maintenance and enrichment planting.

Habitat protection and restoration is urgently needed in India to prevent further species loss as a result of degradation caused due to invasive plant species. The main goal of many habitat restoration models should be to recover a habitat to a state that is self-sustaining, resilient and functional and gives native species opportunities for survival and adaptation in the face of invasive plant invasion and climate change. But the question arises that how to achieve such resilience habitats that will be functional in a potentially climate change. There is no perfect answer to the questions that arise from ecological theory and the conceptual frameworks used in the field of restoration, so any restoration approach should involve a risk assessment of likely outcomes and impacts.

Some of the actions that can be considered during habitat restoration planning to improve short-term resilience and long-term adaptive potential include (Clarke *et al.*, 2010):

- Background to the project, stakeholders involved
- Restoration goals, targets and milestones
- Site location and project boundaries
- Rainfall and other climatic considerations
- Physical properties of the soil and landforms over the site
- Land use history and prior disturbance at and adjacent to the site
- Current location, state and 'trajectory' of native vegetation (if present)
- Condition and distribution of other relevant habitat features currently present

- Proximity to other habitat/remnant vegetation
- Current and potential future threats that need to be addressed in order to reach the restoration goal (include site threats and project risks)
- Management unit locations and their management context (maintain, improve, reconstruct or works exclusion zone)
- Desired habitat goal state (e.g. vegetation composition and structure)
- Management actions, with an implementation schedule prioritized over time and space (with flexibility for adjustment according to adaptive management as the project progresses)
- Standard operating procedures and access to the site
- Indicative resource requirements
- Monitoring and evaluation goals, indicators and schedule
- Location of reference sites (if applicable)
- The process of reporting and review
- Contacts and references (including previous reports)
- Incorporating species with functional traits suited to the likely future climate and disturbance regimes
- Using seed from local and wider gene pools of plant species for revegetation works to improve the viability of species in fragmented environments.

Site assessment: A site assessment will give the information to identify which areas require maintenance of good habitat, improvement of partially degraded habitat and/or reconstruction of degraded areas. Reconstructing degraded sites to be ultimately resilient and functional will require revegetation using tubestock or direct seeding methods. It may involve up to four phases of restoration over a long period of time. The four phases are the:

- Foundation - focussing on manipulation of landform, soil texture, water table, salinity to ensure the nature of underlying factors are appropriate to reach the end goal.

- Early ecosystem establishment - focussing on soil stability, cover and appropriate species mix, e.g. through revegetation

- Intermediate ecosystem stage - focussing on sustainability of system, e.g. success of regeneration processes, decomposition and nutrient cycling.

- Advanced ecosystem stage - focussing on niche habitats, resilience to threats and disturbance.

The standard practices and activities which are used in planning, implementing, monitoring and evaluating ecological restoration projects where professional staff or contractors are engaged are discussed below in details (McDonald *et al.*, 2015):

- Planning and design:

  - Stakeholder engagement: Significant engagement of the stakeholder is to be undertaken at the planning stage of any restoration project. Stakeholders include land, or forest managers, industry interests, neighbours and local community and Indigenous stakeholders.

  - External context assessment: This assessment provides map of the project with respect to its surrounding landscape, identifies ways to optimize colonization and gene flow potential between sites by physically aligning habitats at the restoration site to improve external ecological connectivity with the surrounding landscape and identify mechanisms for the future management of the project along with the management of nearby native ecosystem.

- Ecosystem baseline inventory: This plan involves identification of sites, current conditions which include list of native and non native species, status of current abiotic conditions, relative capacity of the biota, map of areas including priority resilient areas and any distinct spatial zones requiring different treatments, also identifies type and degree of drivers and threats that have caused degradation, damage or destruction on the site and ways to eliminate, mitigate or in some cases adapt to them.
- Reference ecosystem identification: It is a model characteristic of an identified ecosystem that form the target for the restoration project. This involves describing the substrate characteristics like biotic or abiotic, aquatic or terrestrial, ecosystem functional attributes, major characteristic species and assessment of habitat needs. This model is synthesized from information about past, present and anticipated future conditions at the site and similar sites in the region, in consultation with stakeholders.
- Targets, goals and objectives: In order to produce well targeted works and measures whether success has been achieved, this plan identify clearly about the restoration target, goals and objectives.
- Restoration treatment prescription: Plans contain clearly stated treatment prescriptions for each zone, describing what, where and by whom treatments will be undertaken and their order or priority.
- Assessing security of site tenure and of post treatment maintenance scheduling: This restoration plan assess security of tenure of the site and potential for adequate arrangements for ongoing prevention of impacts and maintenance on the site after completion of the project to ensure that the site does not regress into a degraded state.
- Analyzing logistics: Identifies funding, labor and other resource arrangements, undertaking a full risk assessment and identifying a risk management strategy for the project, timetable for the project and permissions, permits and legal constraints applying to the site and the project.
- Review process scheduling: Include a schedule and time frame for review of the plan based on new knowledge, changing environmental conditions and lessons learned from the project.

- Implementation: This phase assures and manages restoration projects in such a way that:
  - No further damage is caused by the restoration work,
  - Treatments are interpreted and carried out responsibly, effectively and efficiently,
  - All treatments are undertaken in a manner that is responsive to natural processes and fosters and protects potential for natural and assisted recovery
  - Corrective changes of direction (to adapt to unexpected ecosystem responses)
  - All projects exercise full compliance with work, health and safety legislation
  - All project operatives communicate regularly with key stakeholders

- Monitoring, documentation, evaluation and reporting:
  - Monitoring: to evaluate restoration outcomes begins at the planning stage with the development of a monitoring plan to identify success or otherwise of the treatments. It include collection of baseline data prior to

works, collecting data at appropriate intervals after works and recording the details of restoration activities.

- Adequate records of treatments are maintained: to ensure adequate implementation, inform adaptive management and enable future evaluation of results relative to treatments.

- Evaluation and documentation of the outcomes: Evaluation is done to adequately assess results from the monitoring and results should be used to inform ongoing management.

- Reporting: Involves preparation of progress reports to convey the information in an accurate and accessible way, customized to the audience and specify the level and details of monitoring upon which any evaluation of success has been based.

- Post-implementation maintenance: Finally, the management body is responsible for ongoing maintenance to prevent deleterious impacts and carry out any required monitoring of the site after completion of the project to ensure that the site does not regress into a degraded state.

CONCLUSION

In India funding for invasive species management efforts is typically limited, it is essential to prioritize those species and populations that are most important to control. Prioritization should be based on potential impacts of invaders and potential for control. Often exotic plant species have both positive and negative effects on native species; therefore it is important to consider these effects before designing any restoration model. So far determining the actual impact of an invasive alien species has not been done completely, particularly for those species which are new to a region and has not been well studied in similar environments.

Scientists and practitioners should continue to integrate the knowledge gained from both successful and unsuccessful restoration efforts. In many cases it will not be possible to eradicate invasive alien species, and sites will require continuous management to reduce their impacts. On the other hand conflicts may arise between invasive species management and protection of native species, and these warrant careful scientific examination. In an ecosystem each and every species have some useful potential which may provide distinct ecosystem services. Although some non native species can cause severe problems that should be taken into account, a wide perspective on the role of each species in an ecosystem is essential. Further systematic analyses including assessment of the values upon which we base priorities for management, coupled with the probability of achieving desired goals, may help to make restoration efforts involving native species more practical and successful.

REFERENCES

Abdulahi, M.M., Ute, J.A., and Regasa, T. (2017). *Prosopis Juliflora*: Distribution, impacts and available control methods in Ethiopia. Tropical and Subtropical Agroecosystems, 20(1):75-89.

Abraham, M., Abraham, C.T. and Joy, P.J. (2002). Natural enemies on *Mikania micrantha* H.B.K. in Kerala. Journal of Tropical Agriculture, 40:39-41.

Adamson, R.M. and Crossley, J.H. (1968). Annual flower plant growth as affected by soil-incorporated herbicides. Weed Science, 16(1):60-2

Ahmad-Faiz, M. A. 1992. Comparison of three weeding methods in rubber cultivation. Planters' Bulletin Rubber Research Institute of Malaysia, 212-213:99-101.

Alex PC, Rajankutty K, Valsala KV, Nair KNM, 1991. Mimosa poisoning in a heifer. Journal of Veterinary and Animal Sciences, 22(1):134-136.

Angiras, N. N. (1998). Restoration of Hill eco-system by integrated management of obnoxious weeds in H.P. In: Proceeding: International Symposium on Sustainable Agriculture in hill areas. HPKV, Palampur.

Babu, S., Love, A. and Babu, C. R., (2009). Ecological restoration of Lantana invaded landscapes in Corbett Tiger Reserve, India. Ecological Restoration, 27, 468–478.

Bambaradeniya CNB, Perera MSJ, Perera WPN, Wickramasinghe LJM, Kekulandala LDCB, Samarawickrema VAP, Fernando RHSS, Samarawickrema VAMPK. (20030. Composition of faunal species in the Sinharaja World Heritage Site in Sri Lanka. Sri Lanka Forester, 26: 21-40. Barrows EM. 1976. Nectar Robbing and Pollination of *Lantana camara* (Verbenaceae). Biotechnology, 8(2): 132-135.

Barua IC, Deka J, Devi M, (2013). Invasive weeds and vegetation dynamics in Assam. In: The role of weed science in supporting food security by 2020. Proceedings of the 24th Asian-Pacific Weed Science Society Conference, Bandung, Indonesia, October 22-25, 2013 [ed. by Bakar, B. H.\Kurniadie, D.\Tjitrosoedirdjo, S.]. Bandung, Indonesia: Weed Science Society of Indonesia, 166-170.

Batish, D.R., Singh, H.P., Kohli, R.K., Johar, V. and Yadav, S. (2004). Management of invasive exotic weeds requires community participation. Weed Technology, 18:1445-1448.

Beeson, C.F.C. and Chatterjee, N.C. (1939). Possibilities of control of Lantana by indigenous insect pest. Indian forest records (new series), 41-84.

Bhagwat, S.A., Breman, E., Thekaekara, T., Thornton, T.F. and Willis, K.J. (2012). A battle lost? Report on two centuries of invasion and management of *Lantana camara* L. in Australia, India and South Africa. PLoS ONE, 7(3):e32407.

BioNet-EAFRINET, 2016.

Biswas, K. and Calder, C.C. (1954). Handbook of common water and Marsh Plants in India and Burma. Health Bull, 24 pp.

Bowmer, K.H. (1992). Aquatic plant management in Australia (not necessarily weed control!). In: Proceedings: First International Weed Control Congress, 2:95-98.

Burkart, A. (1976). A monograph of the genus *Prosopis* (Leguminosae, subfam. Mimosoideae). (Part 1 and 2.) Catalogue of the recognized species of Prosopis. Journal of the Arnold Arboretum, 57:217-246, 450-525.

CABI, (2005). Forestry Compendium. Wallingford, UK: CABI

CABI, (2019). Invasive Species Compendium. Wallingford, UK: CAB International. www.cabi.org/isc.

Chandra SK, (2012). Invasive Alien Plants of Indian Himalayan Region- Diversity and Implication. American Journal of Plant Sciences, 3:177-184.

Chiu, S. B., Sugianto, H. and Yuhdi. (2005). Biocontrol of Siam weed with the gallfly - experience in West Kalimantan and Jambi. Planter, 81(955):643-647.

Cilliers, C.J. and Neser, S., (1991). Biological control of *Lantana camara* (Verbenaceae) in South Africa. Agriculture. Ecosystems & Environment, 37(1-3):57-75.

Clarke, I. Stokes, Z. and Wallace, R. (2010). Habitat Restoration Planning Guide for Natural Resource Managers, Government of South Australia, through Department of Environment and Natural Resources, Adelaide.

Courchamp, F., Fournier, A., Bellard, C., Bertelsmeier, C., Bonnaud, E., Jeschke, and J. M., (2017). Invasion biology: specific problems and possible solutions. Trends in Ecology and Evolution (Amst). 32:13-22.

Cronk, C. B., and J. L. Fuller. (1995). Plant invaders: the threat to natural ecosystems. Chapman and Hall, London.

DAF, 2016. Giant sensitive plant - *Mimosa diplotricha (=Mimosa invisa).* The State of Queensland Department of Agriculture and Fisheries. https://www.daf.qld.gov.au /__data/assets/pdf_file/0017/67121/IPA-Giant-Sensitive-Plant-PP27.pdf

D'Antonio, C. and Meyerson L.A. (2002). Exotic plant species as problems and solutions in ecological restoration: A synthesis. Restoration Ecology, 10: 703-713.

Day MD, Wiley CJ. Playford J, Zalucki MP, (2003). Lantana: current management status and future prospects. Australia: ACIAR Monograph, 102.

Early, R., Bradley, B. A., Dukes, J. S., Lawler, J. J., Olden, J. D., Blumenthal, D. M., et al. (2016). Global threats from invasive alien species in the twenty-first century and national response capacities. Nature Communications. 7:12485.

Ekta.(2014). Dominance of *Prosopis juliflora* (Sw.) D.C in the Delhi Ridge forest of the semi-arid region, India. The Biobrio, 1 (1): 41 – 44.

El-Ghareeb, R. (1991). Vegetation and soil changes induced by *Mesembryanthemum crystallinum* L. in a Mediterranean desert ecosystem. Journal Arid Environment, 20: 321-330.

Ellison, C. and Day, M. (2011). Current status of releases of *Puccinia spegazzinii* for *Mikania micrantha* control. Biocontrol News and Information, 32:1N.

Epstein, G. (2017). Invasive Alien Species Management: A Personal Impasse. Frontiers in environmental science, 5:68.

Ewel, J. J., D. J. O'Dowd, J. Bergelson, C. C. Daehler, C. M. D'Antonio, L. Diego Gomez, D. R. Gordon, R. J. Hobbs, A. Holt, K. R. Hopper, C. E. Hughes, M. LaHart, R. R. Leakey, W. G. Lee, L. L. Loope, D. H. Lorence, S. M. Louda, A. E. Lugo, P. B. Mc-Evoy, D. M. Richardson, and P. M. Vitousek. (1999). Deliberate introductions of species: research needs. Bioscience 49:619–630.

Felker P, McLauchlan RA, Conkey A, Brown S, 1999. Case study: development of a swath harvester for small diameter (<10 cm) woody vegetation. Biomass and Bioenergy, 17:1-17.

Findlay, J. B. R. and Jones, D. (1996). The integrated control of water hyacinth, *Eichhornia crassipes*, in Africa based on Roundup R herbicide treatments. In: Proceeding: 9th international symposium on biological control of weeds, Stellenbosch. 19-26 January 1996. South Africa. 435-440pp.

Flora of Panama, (2016). Flora of Panama (WFO), Tropicos website. Tropicos website. St. Louis, MO and Cambridge, MA, USA: Missouri Botanical Garden and Harvard University Herbaria. http://www.tropicos.org/Project/FOPWFO

Flory, S.L. and Clay, K. (2009). Invasive plant removal method determines native plant community responses. Journal of Applied Ecology, 46:434-442.

Fowler, S.V. (1998). Report on the invasion, impact and control of 'Mexican thorn', Prosopis juliflora, on Ascension Island. Ascot, UK: CABI Bioscience.

Gaikwad, C. B., Kasture, M. C. and Lambade, B. M. (2008). Evaluation of herbicides for control of Parthenium in waste land. Indian Journal of Weed Science, 40(1-2):79-81.

Geesing, M., Khawlani and Abba, M.L. (2004). Management of introduced Prosopis species: Can economic exploitation control an invasive species. Unasylva, 217(55): 36- 44.

Gioria, M., Jarošík, V., Pyšek, P. (2014). Impact of invasions by alien plants on soil seed bank communities: emerging patterns. Perspectives in Plant Ecology, Evolution and Systematics 16:132-142.

Global Invasive Species Database (GISD), (2010). Invasive Species Specialist Group of the IUCN.

Gopal B, (1987). Biocontrol with arthropods. Water hyacinth, 208-230; [2 fig., Aquatic Plant Studies No. 1]

Gopalakrishnan, A., Mayalagu, R., Jun, S., Ajay, P., Balu, A. and Venmathi, M. (2011). Integrated biological control of water hyacinths, Eichhornia crassipes by a novel combination of grass carp, *Ctenopharyngodon idella* (Valenciennes, 1844), and the weevil, *Neochetina* spp. Chinese Journal of Oceanology and Limnology, 29 (1):162–166.

Gordon, B., and Arne, Witt. (2013). Invasive alien plants and their management in Africa Synthesis Report of the UNEP/GEF Removing Barriers to Invasive Plant Management in Africa (RBIPMA) Project, implemented in four African countries (Ethiopia, Ghana, Uganda and Zambia) between 2005 and 2010.

Gujral GS, Vasudevan P, 1983. *Lantana camara* L., a problem weed. Journal of Scientific and Industrial Research, 42:281-286.

Hatterman-Valenti H. and Mayland, P. (2005). Annual flower injury from sublethal rates of dicamba, 2, 4-D, and premixed 2,4-D + mecoprop + dicamba. HortScience, 40(3):680-684.

Hayes L; Fowler SV; Paynter Q; Groenteman R; Peterson P; Dodd S; Bellgard S, (2013). Biocontrol of weeds: achievements to date and future outlook. In: Ecosystem services in New Zealand: conditions and trends [ed. by Dymond, J. R.]. Lincoln, New Zealand: Manaaki Whenua Press, Landcare Research, 375-385.

Henderson, L. (1995). Plant invaders of Southern Africa. Agriculture Research Council, ARC/LNR, Pretoria, South Africa. 55pp.

Henderson, L. (2001). Alien Weeds and Invasive Plants. Plant Protection Research Institute Handbook No. 12. Cape Town, South Africa: Paarl Printers.

Henty EE, Pritchard GH, 1975. Weeds of New Guinea and their Control. Lp, Papua New Guinea: Department of Forests, Division of Botany, Botany Bulletin No.7.

Hiremath A. J., Prasad A. and Sundaram B. (2018). Restoring *Lantana camara* Invaded Tropical Deciduous Forest: The Response of Native Plant Regeneration. Indian Forester, 144 (6) : 545-552.

Hodkinson, I. D. (1991). New World legume-feeding psyllids of the genus *Aphalaroida crawford* (Insecta: Homoptera: Psylloidea). Journal of Natural History, 25(5):1281-1296.

Hoffmann, J. H., Impson, F. A. C. and Moran, V.C. (1993). Competitive interactions between two bruchid species (*Algarobius* spp.) introduced into South Africa for biological control of mesquite weeds (*Prosopis* spp.). Biological Control, 3(3): 215-220.

Holm LG, Plucknett DL, Pancho JV, Herberger JP, (1977). The World's Worst Weeds. Distribution and Biology. Honolulu, Hawaii, USA: University Press of Hawaii.

Howard RA, (1969). A checklist of cultivar names in the genus Lantana. Arnoldia, 29(11):73-109.

Impson, F. A. C., Kleinjan, C. A., Hoffmann, J. H. and Post, J. A. (2008). *Dasineura rubiformis* (Diptera: Cecidomyiidae), a new biological control agent for *Acacia mearnsii* in South Africa. South African Journal of Science, 104 (7/8): 247-248.

Impson, F.A. C., Post, J. A. and Hoffmann, J. H. (2013). Impact of the flower-galling midge, *Dasineura rubiformis* Kolesik, on the growth of its host plant, *Acacia mearnsii* De Wild, in South Africa. South African Journal of Botany, 87:118-121.

Ismail, A.A. (2001). Impact and management of selected alien and invasive weeds in Malaysia with some action plans instituted for biological diversity. In: Proceedings of the Third International Weed Science Congress. Oxford, UK: International Weed Science Society, CD-ROM, MS No. 446.

ISSG, 2017. Global Invasive Species Database (GISD). Invasive Species Specialist Group of the IUCN Species Survival. http:// www.issg.org/database/welcome/

Javaid, A. (2007). Efficacy of some chemical herbicides against *Parthenium hysterophorus* L. Pakistan Journal of Weed Science Research, 13:93-98.

Jeyalakshmi, C., Doraisamy, S. and Paridasan, V. V. (2005). Lasidiplodia theobromae: a potential pathogen of *Parthenium hysterophorus* Linnaeus. In: Proceeding: Second International Conference on Parthenium hysterophorus Management. December 5-7. Bangalore (Karnataka), India, 271-272.

Johnson, M.F. 1971. A monograph of the genus *Ageratum* L. (Compositae-Eupatorieae). Annals Missouri Botanical Garden, 58:6-88.

Joshi, S. (1991) Biological control of *Parthenium hysterophorus* L. (Asteraceae) by Cassia uniflora Mill (Leguminosae) in Bangalore, India. Tropical Pest Management, 37:182-184.

Julien, M. H., Sfroza, R., Bon, M. C., Evans, H. C., Hatcher, P. E.,. Hinz, H. L. and Rector, B. G. (Eds.), CAB International, Wallingford, UK, France, 384-389pp.

Julien, M.H. and Broadbent, J.E. (1980). The biology of Australian weeds 3. *Alternanthera philoxeroides* (Mart.) Griseb. Journal of the Australian Institute of Agricultural Science, 46(3):150-155.

Julien, M.H. ed, (1992). Biological control of weeds: A world wide catalogue of agents and their target weeds. 3rd edition. Wallingford, UK: CAB International.

Julien, M.H., Skarratt, B., and Maywald, G.F. (1995). Potential geographical distribution of alligator weed and its biological control by *Agasicles hygrophila*. Journal of Aquatic Plant Management, 33:55-60.

Kathiresan, R.M., (2000). Allelopathic potential of native plants against water hyacinth. Crop Protection, 19(8):705-708.

Kaur, M., Aggarwal, N.K., Kumar, V., and Dhiman, R. (2014). Effects and Management of *Parthenium hysterophorus*: A Weed of Global Significance. International Scholarly Research Notices, 2014:12pp.

Khan, H., Khan, B. M., Hassan, G. and Khan, M. A. (2012). Chemical control of *Parthenium hysterophorus* L. at different growth stages in non-cropped area. Pakistan Journal of Botany, 44(5):1721-1726.

Klinken, R.D. van., Hoffmann, J.H., Zimmermann, H.G. and Roberts, A.P. (2009). *Prosopis* spp. (Leguminosae). In: Biological Control of Tropical Weeds Using Arthropods (Muniappan, R. Reddy, G. V. P. Raman, A. Eds.). Cambridge, UK, 353-377.

Lakshmi, C. and Srinivas, C. R. (2007). Type I hypersensitivity to Parthenium hysterophorus in patients with parthenium dermatitis. Indian Journal of Dermatology, Venereology and Leprology, 73(2):103-105.

Lima, P. C. F. 1994. Comportamento silvicultural de especies de Prosopis, em Petrolina-PE, Region Semi-Arida Brasileira. Ph.D., Thesis. Curitiba, Brazil: Universidade Federal do Parana.

Love Amit, Suresh Babu and C. R. Babu (2009). Management of Lantana, an invasive alien weed, in forest ecosystems of India. Current science, vol. 97 (10: 25): 1421-1429.

Mandal, F. (2011). The management of alien species in India. International Journal of Biodiversity and Conservation. 3:467-473.

Mangoensoekarjo, S. (1978). Mile-a-minute (*Mikania micrantha* H. B.K.) control in immature oil palm. In: Proceeding: Plant Protection Conference. Malaysia, 381-387.

Mathur, G., Mohan Ram, H.Y. (1986). Floral biology and pollination of *Lantana camara*. Phytomorphology, 36:79-100.

McGeoch, M. A., Genovesi, P., Bellingham, P. J., Costello, M. J., McGrannachan, C., and Sheppard, A. (2016). Prioritizing species, pathways, and sites to achieve conservation targets for biological invasion. Biological Invasions 18:299-314.

McNeely, J.A., H.A. Mooney, L.E. Neville, P. Schei, and J.K.Waage (eds.) 2001. A Global Strategy on Invasive Alien Species. IUCN Gland, Switzerland, and Cambridge, UK. x + 50 pp.

McNeish, R. E., Benbow, M. E. and McEwan R.W. (2017). Removal of the Invasive Shrub, *Lonicera maackii* (Amur Honeysuckle), from a Headwater Stream Riparian Zone Shifts Taxonomic and Functional Composition of the Aquatic Biota. Invasive Plant Science and Management, 10 (03): 232.

Mohan Ram, H.Y., Mathur, G. (1984). Flower colour changes in *Lantana camara*. Journal of Experimental Botany, 35:1656-1662.

Muniappan R, Viraktamath CA, (1993). Invasive alien weeds in the Western Ghats. Current Science, 64(8):555-558.

Muniappan R; Marutani M. (1991). Mechanical, cultural and chemical control of Chromolaena odorata. In: Proceeding: Second International Workshop on *Chromolaena odorata* (Muniappan R, Ferrar P, Eds.). Biotrop Special Publication, 44:79-82.

Napompeth B, Kongsawat C, and Iamsupasit N. (2003). Current status on alien species management in Thailand. A paper presented at the 20th Pacific Science Congress, 17-21 March, Bangkok, Thailand, 19-25pp.

Narayan, P.S., Anitha K., and Narendra Prasad, S. (2007). Water hyacinth (*Eichhornia crassipes*) – management of an invasive weed, the Indian scenario.

Naudiyal, N., J. Schmerbeck and S. Gärtner. (2017). What influences the plant community composition on Delhi ridge? The role played by Prosopis juliflora and anthropogenic disturbances. Tropical Ecology 58: 33–43.

Omokhua, A.G., McGaw, L.J., Finnie, J.F., and Van Staden, J. (2016). *Chromolaena odorata* (L.) R.M. King & H. Rob. (Asteraceae) in sub-Saharan Africa: A synthesis and review of its medicinal potential. The Journal of Ethnopharmacology, 13(183):112-122.

Panchal, Y.C. and Shetty, P. (1977). Chemical control of *Prosopis juliflora* (Sw) DC. Program and Abstracts of Papers, Weed Science Conference and Workshop in India, No. 153.

Pandey, V. C., P. Prakash, O. Bajpai, A. Kumar and N. Singh. (2015). Phytodiversity on fly ash deposits: evaluation of naturally colonized species for sustainable phytorestoration. Environmental Science and Pollution Research, 22:2776-2787.

Parsons, W.T., and Cuthbertson, E.G. (1992). Noxious Weeds of Australia. Melbourne, Australia: Inkata Press, 692pp.

Pasiecznik, N.M., Felker, P., Harris, P.J.C., Harsh, L.N., Cruz, G., Tewari, J.C., Cadoret, K. and Maldonado, L.J. (2001). The *Prosopis juliflora - Prosopis pallida* Complex: A Monograph. Coventry, UK: HDRA.

Paynter, Q. and Flanagan, G.J. (2004). Integrating herbicide and mechanical control treatments with fire and biological control to manage an invasive wetland shrub, *Mimosa pigra*. Journal of Applied Ecology, 41: 615-629.

Picman, J. and Picman, A. K.(1984). Autotoxicity in *Parthenium hysterophorus* and its possible role in control of germination. Biochemical Systematics and Ecology, 12(3):287-292.

Polk, K. L. and Ueckert, D. N. (1973). Biology and ecology of a mesquite twig girdler, *Oncideres rhodosticta*, in West Texas. Annals of the Entomological Society of America, 66(2):411-417.

Priyanka Neena and Joshi, P. K. 2013. A review of *Lantana camara* studies in India. International Journal of Scientific and Research Publications, 3(10).

Raghubanshi, A.S. and Tripathi, A. (2009). Effect of disturbance, habitat fragmentation and alien invasive plants on floral diversity in dry tropical forests of Vindhyan highland: a review. Tropical Ecology, 50(1): 57-69.

Rai, P. and Kanodia, K.C. (1980). Seasonal variation in forage production and chemical constituents in the tropical legumes under rainfed condition. Indian Journal of Ecology, 7:268-275.

Rai, P. K. (2013). Plant invasion ecology: impacts and sustainable management. New York: Nova Science Publisher.196.

Ray, P. and Gour, H. N. (2012). Integrated management of *Parthenium hysterophorus* L. (Asteraceae): a weed of worldwide significance. Indian Society of Mycology and Plant Pathology, 5:605-632.

Russell, J. C., and Blackburn, T. M. (2017). Invasive alien species: denialism, disagreement, definitions, and dialogue. Trends in Ecology and Evolution (Amst). 32:312-314.

Sahu, P.K., Singh, J.S. (2008). Structural attributes of lantana-invaded forest plots in Achanakmar–Amarkantak Biosphere Reserve, Central India. Current Science, 94 (4): 494-500.

SANBI, (2016). South African National Biodiversity Institute (SANBI).Declared weeds and alien invader plants. http://www.plantzafrica.com/miscell/aliens1.htm

Sankaran, K. V. (1999). Mikania management calls for biocontrol. Biocontrol News and information, 22(3):15-21.

Sankaran, K. V. and Pandalai, R.C. (2004). Field trials for controlling *Mikania micrantha* in forest plantations and natural forests in Kerala, KFRI Report No 265. KFRI, India, 52pp.

Sankaran, K., Puzari, K., Ellison, C., Kumar, P. and Dev, U. (2008). Field Release of the Rust Fungus *Puccinia spegazzinii* to Control *Mikania micrantha* in India: Protocols and Raising Awareness, Proceedings of the XII International Symposium on Biological Control of Weeds.

Sannamarappa, M. (1987). Effect of green manuring on the production of areca nut. Indian Cocoa, Arecanut and Spices Journal, 10:67-70.

Sellers B.A. and J.A. Ferrell. 2010. UF-IFAS Bookstore Pub SP 457.

Shanwad, U.K., Chittapur, B.M., Honnalli, S.N. and Shankergoud I. and Tegegnework G. (2015). Management of *Prosopis juliflora* through Chemicals: A Case Study in India. Journal of Biology, Agriculture and Healthcare, 5(23).

Sharma, O.P. (1988). How to combat Lantana (*Lantana camara* L.) menace- A current perspective. Journal of Scientific and Industrial Research, 47:611-616.

Shine, C. (2005) Overview of the management of invasive alien species from the environmental perspective. In: IPPC Secretariat. 2005. Identification of risks and management of invasive alien species using the IPPC framework. Proceedings of the workshop on invasive alien species and the International Plant Protection Convention, Braunschweig, Germany, 22-26 September 2003. Chapter 3. FAO, Rome.

Simberloff, D. (2003). Eradication-preventing invasions at the outset. Weed Science, 51:247-253.

Singh, H.P., Batish, D.R., Pandher, J.K. and Kohli, R.K. (2003). Assessment of allelopathic properties of *Parthenium hysterophorus* residues. Agriculture, Ecosystem and Environment, 95:537-541.

Singh, H.P., Batish, D.R., Setia, N. and Kohli, R.K. (2005). Herbicidal activity of volatile oils from *Eucalyptus citriodora* against *Parthenium hysterophorus.* Annals of Applied Biology, 146:89-94.

Stirton, C.H. (1979). Taxonomic problems associated with invasive alien trees and shrubs in South Africa. In: Proceedings of the 9th Plenary Meeting AETFAT (Association pour l'étude taxonomique de la flore d'Afrique tropicale, Brussells, Belgium), 218-219

Sushilkumar, (2005). Biological control of Parthenium through *Zygogramma bicolorata*. National Research Centre for Weed Science, 89pp.

Swamy, P. S. and Ramakrishnan, P. S. (1987). Effect of fire on population dynamics of Mikania micrantha H.B.K. during early succession after slash and burn agriculture (jhum) in northeastern India. Weed Research, 27:397-404.

Tacio, H.D. (2009). Water Hyacinth Ecological Value, Environmental Impacts. Article.

Tewari, J.C., Harris, P.J.C., Harsh, L.N., Cadoret, K. and Pasiecznik, N.M., (2000). Managing *Prosopis juliflora* (Vilayati babul): a Technical Manual. CAZRI, Jodhpur, India and HDRA, Coventry, UK.

Thomas, G.V. and George, M. (1990). Basin management using green manure legumes for root (wilt) affected coconut palms. Indian Coconut Journal (Cochin), 20(11):7-8

Turner, P.J. and Virtue, J.G. (2009). Ten year post-fire response of a native ecosystem in the presence of high or low densities of the invasive weed, *Asparagus asparagoides*. Plant Protection Quarterly, 24: 20-26.

USDA-ARS, (2016). Germplasm Resources Information Network (GRIN). National Plant Germplasm System. Online Database. Beltsville, Maryland, USA: National Germplasm Resources Laboratory.

Van Wilgen, B., Richardson, D., and Higgins, S. (2001). Integrated control of invasive alien plants in terrestrial ecosystems. Land use and Water Resources Research, 1(5): 1-6.

Waterhouse, B. M. and Zeimer, O. (2002). 'On the brink': the status of *Chromolaena odorata* in northern Australia. In: Zachariades, C., Muniappan, R., Strathie, L.W., (eds.). Proceedings of the Fifth International Workshop on Biological Control and Management of Chromolaena odorata. Pretoria, South Africa: ARC-Plant Protection Research Institute, 29-33.

Waterhouse, D.F. and Norris, K.R. (1987). Biological control: Pacific prospects, 454pp.

Weber, E. (2003). Invasive plant species of the world: A reference guide to environmental weeds. Wallingford, UK: CAB International, 548pp.

Wittenberg, R. and M.J.W. Cock, (2001). Invasive alien species: A toolkit of best prevention and management practices. Global Invasive Species Programme, CAB International, Wallingford, Oxon, UK.

Wolverton, B.C., and McDonald, R.C. (1979). Water hyacinth (*Eichhornia crassipes*) productivity and harvesting studies. Economic Botany, 33:1-10.

Yasotha,.D. and Lekeshmanaswamy, M. (2012). Impact of Neochetina eichhorniae Warner. on Biological Control of Water Hyacinth (*Eichhornia crassipes* (Mart.) Solms.) of Singanallur pond, Coimbatore, Tamil Nadu, India. Indian Journal of Natural Sciences International Bimonthly, 1I (10): 721-726.

Yau-Lun Kuo, Chen, C. C. Lin (2002). Using a consecutive-cutting method and allelopathy to control the invasive vine, Mikania micrantha H.B.K., Taiwan Journal of Forest Science 17(2):171-181.

Zachariades, C. and Goodall, J. M. (2002). Distribution, impact and management of *Chromolaena odorata* in southern Africa. In: Zachariades, C., Muniappan, R., Strathie, L.W. (eds.). Proceedings of the Fifth International Workshop on Biological Control and Management of Chromolaena odorata. Pretoria, ARC-Plant Protection Research Institute, 34-39.

Zavaleta, E. S., Hobbs, R. J., and Mooney, H. A. (2001). Viewing invasive species removal in a whole-ecosystem context. Trends in Ecology and Evolution, 16(8):454-459.

Zhang, L.Y., Ye, W.H., Cao, H.L. and Feng, H.L. (2004). *Mikania micrantha* H. B. K. in China - an overview. Weed Research, 44:42-49.

Zhou Bing; Chen Jie; Ma ShengPing; Yin ShuaiWen; Wang Ning, (2016). Pathogenicity and culture condition of different isolates of *Alternaria alternata* on *Alternanthera philoxeroides.* Southwest China Journal of Agricultural Sciences, 29(2):321-326.

10 POLICIES, INSTRUMENTS AND INSTITUTIONS PERTAINING TO INVASIVE ALIEN SPECIES MANAGEMENT: A SYNTHESIS

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INTRODUCTION

The versatile struggle for the management of invasive alien species has been at the apex of policy programme all over the world. Methods to control, eradicate and prevent invasive alien species are one of the main challenges that need to be addressed in policy formation. In the developing countries the policy challenge posed by invasive species is a serious issue as they arise due to prevailing complex social, economic and political problems (Chenje and Mohamed-Katerere, 2006).The complication pose by invasive species regarding policy comes especially when they have both beneficial and harmful implications like, *Prosopis juliflora* is one such species which is now a policy dilemma for many countries where it is introduced. The issue of some invasive species like *Prosopis juliflora, Lantana camara* etc. in India is particularly interesting as they have shown to impact biodiversity negatively but in some areas they are being utilized by the low income people to support their livelihood.

INTERNATIONAL POLICIES AND INSTRUMENTS RELATED TO INVASIVE ALIEN SPECIES

Several international binding and nonbinding instruments, have been developed to deal with certain aspects of the problem of IAPS. The most inclusive is the 1993 Convention on Biological Diversity (CBD), which calls on its parties – 178 governments as of year 2000 – to *"prevent the introduction, control or eradicate those alien species which threaten ecosystems, habitats, or species"* (Article 8h). A much older instrument is the 1952 International Plant Protection Convention (IPPC), which applies primarily to plant pests. This IPPC was extensively revised in 1997 to meet some of the new challenges of plant pests.

The Convention on Biological Diversity (CBD)

It was one of the major results of the UN Conference, held in Rio de Janeiro in 1992 on Environment and Development. Coming into force in 1993, the CBD has been ratified by nearly 180 countries. The CBD commits to three major goals which are; to take appropriate measures to conserve biological diversity, ensure the sustainable use of biological resources, and promote the fair and equitable sharing of benefits arising from the utilization of genetic resources. Under the CBD, governments agree to prepare national biodiversity strategies and action plans; identify genomes, species, and ecosystems crucial for conservation and sustainable use; monitor biodiversity and factors that are affecting biological systems; establish effectively managed systems of protected areas; rehabilitate degraded ecosystems; exchange information, conduct public information programmes; and various other activities for implementing the objectives of the CBD. The convention's governing body is the Conference of the Parties (COP), consisting of all governments (and regional economic integration organizations) that have ratified the treaty. This ultimate authority reviews progress under the Convention, identifies new priorities, and sets work plans for members. The COP can also make amendments to the Convention, create expert advisory bodies, review progress reports by member nations, and collaborate with other international organizations and agreements. The other main bodies of CBD, are Secretariat, based in Montreal, Canada, Subsidiary Body for Scientific, Technical and Technological Advice (SBSTTA) and Subsidiary Body on Implementation (SBI). The Subsidiary Body on Scientific Technical and

Technological Advice (SBSTTA) of the CBD meets periodically and addresses key issues, including invasive aliens. The CBD has also established an interim financial mechanism, the Global Environment Facility (GEF), which provides approximately US$100 million per year to projects for implementing the Convention in developing countries (http://www.biodiv.org); (Mc Neely *et al.*, 2001).

The Conference of the Parties (COP)

According to the Convention on Biological Diversity (CBD) has recognized that there is an urgent need to address the impact of invasive alien species (IAS), and established IAS as a cross-cutting issue at its fourth meeting. The decision of COP 6 included adoption of Guiding Principles for the Prevention, Introduction and Mitigation of Impacts of Alien Species that Threaten Ecosystems, Habitats or Species (decision VI/23);https://www.cbd.int/decision/cop/?id=7197.

- The guiding principle 1 is based on Precautionary approach- the concept is *if an alien species has a suspected risk of causing harm to the ecosystem, habitat or native species, the proof of burden about "the introduction is NOT harmful" falls on those who introduce the alien species.*

  In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

- The guiding principle 2 is based on Three-stage hierarchical approach- the concept is *Response to invasive alien species based on prevention as the first line of defense, early detection and rapid action when prevention fails, eradication if feasible and, finally, management and containment of established invasions.*

- The guiding principle 3 is based on Ecosystem approach- the concept is *Management of invasive species is not solely based on removal or eradication of invading species but also considers the invaded ecosystem, involves communities and stakeholders and adopts a multi-sectoral approach. The integrated management of land, water and living resources will effectively support the implementation of the CBD and its Strategic Plan for Biodiversity 2011-2020.*

- The guiding principle 4 is based on State responsibility

  Concept: *Provision of measures that falls in each responsible authority on environment, agriculture, trade, transport, industry, science, health… can reduce risks and impact of invasive alien species, including pests and diseases.*

- The guiding *principle 5 is based on Research and monitoring – the concept is to develop an adequate knowledge base to address the problem and appropriate research on and monitoring of alien invasive species should be undertaken. This should document the history of invasions (origin, pathways and time-period), characteristics of the alien invasive species, ecology of the invasion, and the associated ecological and economic impacts and how they change over time. Monitoring is the key to early detection of new alien species. It requires targeted and general surveys, which can benefit from the involvement of local communities.*

- The guiding principle 6 is based on Education and public awareness

  Concept: *Citizens and stakeholders of biodiversity can take effective steps with sound information on invasive alien species, pests and diseases, collectively.*

- The guiding principle 7 is based on Border control and quarantine measures

  Concept: *International trade, transport and tourism are pathways of invasive alien species, including pests and diseases. Border controls and quarantine measures for pests and diseases can include invasive alien species in the work of border controls to stop entries of invasive alien species and suspected alien species.*

- The guiding principle 8 is based on Exchange of information

  Concept: *Surveillance (monitoring and reporting on invasions) is fundamental mechanism to manage invasive alien species, including pests and diseases. Information on invasive species with correct taxonomic name and geographic reference is critical importance for prevention.*

- The guiding principle 9 is based on Cooperation, including capacity-building

  Concept: *cooperative effort between two or more countries, such as:*

  (a) Where a State of origin is aware that a species being exported has the potential to be invasive in the receiving State, the exporting State should provide information, as available, on the potential invasiveness of the species to the importing State. Particular attention should be paid where exporting Parties have similar environments; (b) Agreements between countries, on a bilateral or multilateral basis, should be developed and used to regulate trade in certain alien species, with a focus on particularly damaging invasive species; (c) States should support capacity-building programmes for States that lack the expertise and resources, including financial, to assess the risks of introducing alien species. Such capacity-building may involve technology transfer and the development of training programmes.

- The guiding principle 10 is based on Intentional introduction

  Concept: *Intentional introduction of the known invasive species in a recipient/importing country could be intercepted by the national authority. Suspected alien species could be subjected to appropriate risk analysis process prior to importation/introduction (Note that burden of proof is with the proposer of the introduction or be assigned as appropriate by the recipient State).*

- The guiding principle 11 is based on Unintentional introduction

  Concept: *Common pathways of unintentional introduction include: escape from confined condition; transport-stowaway (e.g. ballast water, biofauling, hitch-hikers); transport-contamination (e.g. wood packaging, contaminated timber, soil or media). Appropriate pathway management measures need to be in place.*

- The guiding principle 12 is based on Mitigation of impacts

  Concept: *Once the establishment of an invasive alien species has been detected, States, individually and cooperatively, should take appropriate steps such as eradication, containment and control, to mitigate adverse effects.*

- The guiding principle 13 is based on Eradication

  Concept: *The best opportunity for eradicating invasive alien species is in the early stages of invasion, when populations are small and localized; hence, early detection systems focused on high-risk entry points can be critically useful while post-eradication monitoring may be necessary.*

- The guiding principle 14 is based on Containment

  Concept: *When eradication is not feasible, limiting the spread (containment) of invasive alien species is an appropriate strategy in cases where the range of the organisms or of the population is small enough. Regular monitoring is essential and it needs to be linked with rapid response to eradicate in any new area of infestation.*

- The guiding principle 15is based on Control

  Concept: *When complete eradication nor containment is possible, reducing the damage caused, as well as reducing the number of the invasive alien species would be an option.*

Aichi Targets

In the COP -10 meeting, the parties agreed that some short term (By the year 2020) plan which is officially known as

Box 1. Actions to enhance progress towards the Aichi Biodiversity target

- *Raising awareness among policy makers, the general public and potential importers of alien species, of the impacts of invasive alien species, including the possible socio-economic costs and the benefits of taking action to prevent their introduction or to mitigate their impacts, such as by publicizing nationally relevant case studies*
- *Increasing efforts to identify and control the main pathways responsible for the introduction of alien species, including through the development of border control or quarantine measures to reduce the likelihood of potentially invasive alien species being introduced and making full use of risk analysis and existing relevant international standards*
- *Putting in place measures for the early detection and rapid response to species invasions*
- *Identifying and prioritizing those invasive alien species with the greatest potential to cause negative impact on biodiversity that are established in the country, and developing and implementing plans for their eradication or control, prioritizing protected areas and other areas of high biodiversity value for eradication or control measures*
- *Developing lists of alien species known to be invasive (or assessing existing lists for their completeness and accuracy) and making them widely available (Target 19), such as through the Global Invasive Alien Species Information Partnership.*

Source: https://www.cbd.int/invasive/doc/cbd-patbf-brochure-en.pdf

The International Plant Protection Convention (IPPC)

Is a multilateral treaty which is in force since 1952. With 111 governments as Contracting Parties, the purpose of the Convention is *"to secure common and effective action to prevent the spread and introduction of pests of plants and plant products and to promote appropriate measures for their control".* Defining pest as *"any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products",* the implementation of the Convention has applied mainly to crops, but it also extends to the protection of natural flora. Thus the scope of the IPPC covers any invasive alien species that may be considered to be a plant pest. The IPPC Secretariat, housed at FAO in Rome, facilitates the development of internationally agreed upon standards for the application of phytosanitary measures in international trade to prevent and control the spread of plant pests (many of which are invasive alien species). The standards developed under IPPC are recognized by the World Trade Organization under the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) (http://www.ippc.int);(Mc Neely *et al.*,2001).

In addition, the growing impact of IAS equally on global economies and the environment suggests that these international instruments have been insufficient to prevent and combat IAS effectively. Furthermore, expanding international trade is moving ever more organisms more rapidly around the world, thereby increasing the threat of these species to native ecosystems and potentially overwhelming government efforts to prevent unwanted invasions. In response to these concerns, the global scientific community established the Global Invasive Species Programme (GISP) in 1997.

The Global Invasive Species Programme (GISP)

It was initially developed in January 1996 and established in 1997 to address the global threats caused by invasive alien species and to provide support to the implementation of Article 8(h) of the Convention on Biological Diversity. GISP is operated by a consortium of the Scientific Committee on Problems of the Environment (SCOPE), CAB International (CABI), and the World Conservation Union (IUCN), in partnership with the United Nations Environment Programme (UNEP). GISP is a component of DIVERSITAS, an international programme on biodiversity science. GISP seeks to improve the scientific basis for decision making on invasive species; develop capacities to employ early warning and rapid assessment and response systems; enhance the ability to manage invasives; reduce the economic impacts of invasives and control methods; develop better risk assessment methods; and strengthen international agreements. GISP strives to develop public education about invasive species, improve understanding of the ecology of invasives, examine legal and institutional frameworks for controlling invasives, develop new codes of conduct for the movement of species, and design new tools for quantifying the impact of invasives. GISP involves the voluntary contribution from a substantial group of scientists, lawyers, and managers from all parts of the world (http://www.stanford.jasper.edu/gisp/);(Mc Neely *et al.*,2001).

GISP has contributed widely to the knowledge and awareness of IAS and has prepared a guide, *"Invasive Alien Species: A Toolkit of Best Prevention and Management"* to address the problem. This guide is designed to aid in the elaboration and adoption of an effective national strategy by pointing to experiences in various nations (Wittenberg *et al.*; 2001). Many challenges, however, still need to be further addressed, and a continuation of the program is recommended. They have proposed activities to implement five global initiatives:

- Global access to information on invasive alien species threats and their prevention and management
- Directed action at key pathways of invasive alien species introduction, through public and private sector cooperation.

- Acceleration of critical research and its dissemination
- Awareness-raising and support to policy development
- Building cooperation between institutions towards a global bio security platform to mitigate the threat of invasive alien species

This global programme aims to help governments and development agencies to identify and initiate national and regional projects in order to mitigate threats posed by invasive alien species. It will also provide support to the existing projects and initiatives and will develop national and international capacity and international networking through the utilization and adaptation of the GISP Toolkit of Prevention and Best Management Practices, and other elements developed in Phase I and will use outputs generated by international GISP activities (McNeely *et al.*, 2001).

The International Union for Conservation of Nature (IUCN) and IAS

The efforts of IUCN regarding IAS is mainly focused on achieving Aichi Target 9 and in order to achieve this IUCN has been working in three major areas, providing scientific knowledge, engaging in and supporting national and regional policy development, and action on the ground. A large amount of the work IUCN undertakes on IAS is through the Invasive Species Specialist Group (ISSG), which is a global network of scientific and policy experts on invasive species. Organized by the IUCN Species Survival Commission, the ISSG aims to reduce threats to natural ecosystems and the native species they contain by increasing awareness of invasive alien species and ways to prevent, control or eradicate them (https://www. iucn.org/theme/species/our-work/invasive-species).

There are number of knowledge databases developed by IUCN which offer critical support to decision making processes related to IAS like The Global Invasive Species Database and The Global Register of Introduced and Invasive Species and some other like the Island Biodiversity and Invasive Species database, IAS Pathways Management Resource and Classifying the environmental impact of different IAS are under development.

Global database on invasive alien species and database system

Global Invasive Species Database (GISD) provide information on species, their taxonomy and ecology, information on their native and invaded habitat with location, impacts, along with reports on management methods. This database is searchable, user- friendly, quick, reliable and is designed in such a way that additions can be made in future.

Source: (http://www.issg.org/database)

IUCN is the leading provider of conservation data, assessments and analysis, and an implementing agency of conservation projects around the world. IUCN champions nature's role in achieving the Sustainable Development Goals (SDGs). It also serves as an official agency monitoring progress towards biodiversity-related targets.

The Sustainable Development Goals (SDGs) objective was to produce a set of universal goals that meet the urgent environmental, political and economic challenges facing our world. One of the SDG's goals *#15 Life on land Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.*

NATIONAL

Conventions and legislations to support management of IAS in India:

Our country is signatory to different international Conventions, Treaties and Agreements dealing with invasive species such as Convention on Biological Diversity (Nairobi, 1992), Cartegna Protocol on Biosafety to the Convention on Biological Diversity (Montreal, 2000), United Nations Convention on the Law of the Sea (Montego Bay, 1982), The Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar, 1971), Convention on Migratory Species of Wild Animals (Bonn, 1979), International Union for Conservation of Nature (IUCN)- Guidelines for the Prevention of Biodiversity Loss caused by Alien Invasive, Agenda 21-United Nations Conference on Environment and Development (Rio, 1992), Asia Pacific Forest Invasive Species Network and FAO Regional office, Bangkok (http://apfisn.net/sites/default/files/India.pdf). Several organizations deal with invasion research such as World Conservation Union (WCU), Global Invasive Species Programme (GISP), Invasive Species Advisory Council (ISAC), Invasive Species Specialist Group (ISSG) and National Invasive Species Council, 2001. Further Article 8(h) of the CBD calls on member governments to *'as far as possible and appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species.'*

We have a number of different legislations relating to invasive species like-The Destructive Insects and Pests Act, 1914 and amendments; Indian Forest Act, 1927; Wildlife (Protection) Act, 1972; Forest (Conservation) Act, 1980; Environment Protection Act, 1986; The Plants, Fruits and Seeds (Regulation of Import into India) Order 1989 (PFS Order 1989); Livestock Importation Act, 1898 and the Livestock Importation (Amendment) Ordinance, 2001; National Policy and Macro level Action Strategy on Biodiversity, 1999; The Biological Diversity Act, 2002; The Plant Quarantine (Regulation of Import into India) Order, 2003; National Environment Policy, 2004; The Prevention and Control of Infectious and Contagious Disease in Animals Act, 2009 (Priyanka and Joshi, 2013). Also, we have a number of different agencies for preventing the introduction of invasive species and for management and control of invasive species. These include the Ministry of Environment Forests and Climate Change, Government of India, the National Bureau of Fish Genetic Resources, the Plant Quarantine Organisation of India and various departments of the Ministry of Agriculture. The Indian Council of Forest Research and Education, Dehradun has established 'Forest Invasive Species Cell'. The major objectives of this cell are to establish database on forest invasive species in India, networking and capacity building towards management of invasive species and development of better technology to eradicate invasive species. However, more coordinated efforts are required for effective management of the invasive alien species and India is still lacking on a core policy and legislative framework to manage the invasive alien species. Moreover one of the major obstacles for policy development and implementation has been a lack of awareness of the causes and consequences of biological invasion taking place in different regions.

India's National Biodiversity Action Plan (NAP)

The Convention on Biological Diversity (COD) mandates each Party to prepare a National Biodiversity Strategy and Action Plan (NASAL) or an equivalent instrument, and to ensure that this strategy is mainstreamed into relevant sectoral or cross-sectoral plans, programmes and policies. NBSAPs are the principal instruments for implementing the Convention at the national level. Accordingly, the Government of India developed a National Policy and Macro level Action Strategy on Biodiversity in 1999 (MoEF 1999) within five years of ratifying the CBD. A document was prepared through an extensive consultative process involving various stakeholders, is a macro-level statement of policies and strategies needed for conservation and sustainable use of biological diversity. Subsequently, the Ministry of Environment and Forests (MoEF) implemented an externally-aided project, the NBSAP, from 2000 to 2004. Following India's adoption of the National Environment Policy (NEP) in 2006, a National Biodiversity Action Plan

(NBAP) was prepared by updating the 1999 document (MoEF 1999), and by using the final technical report of the NBSAP project, in order to achieve consonance between the NBAP and the NEP 2006. India's NBAP, formulated through a comprehensive inter-ministerial process, was approved by Government of India (GoI) in 2008 (MoEF 2008, http://nbaindia.org/uploaded/Biodiversityindia/NBAP.pdf).

The NBAP (2008) identifies threats and constraints in biodiversity conservation taking into cognizance the existing legislations, implementation mechanisms, strategies, plans and programmes, based on which action points have been designed (Box. 1).

Action points of India's National Biodiversity Action Plan 2008 related to the Regulation of introduction of invasive alien species and their management:

- *Develop a unified national system for regulation of all introductions and carrying out rigorous quarantine checks.*
- *Strengthen domestic quarantine measures to contain the spread of invasive species to neighbouring areas.*
- *Promote intersectoral linkages to check unintended introductions and contain and manage the spread of invasive alien species.*
- *Develop a national database on invasive alien species reported in India.*
- *Develop appropriate early warning and awareness system in response to new sightings of invasive alien species.*
- *Provide priority funding to basic research on managing invasive species.*
- *Support capacity building for managing invasive alien species at different levels with priority on local area activities.*
- *Promote restorative measures of degraded ecosystems using preferably locally adapted native species for this purpose.*
- *Promote regional cooperation in adoption of uniform quarantine measures and containment of invasive exotics.*

Source: MoEF 2008

National Biodiversity Target 4

It corresponding to Aichi Biodiversity Target 9 according to which *"by 2020, invasive alien species and pathways are identified and strategies to manage them developed so that populations of prioritized invasive alien species are managed".* The organizations and institutions such as MoEF & CC, DoS, ICFRE, WII, NBA, Center for Marine Living Resources and Ecology (CMLRE), National Institute of Oceanography (NIO), SACON, various Universities and State Forest departments can contribute for achieving the target.

A MAJOR GAP

In India Invasive alien species eradication is underfunded. The National Biodiversity Authority (NBA) is hosting the BIOFIN (Biodiversity Finance Initiative), a global United Nations Development Programme (UNDP) initiative that helps the country generate national level expenditure data on biodiversity. Since 2015, the NBA has been assessing the cost of implementation of the National Biodiversity Targets.

INTERNATIONAL AND REGIONAL INSTRUMENTS AND INSTITUTIONS PERTAINING TO ALIEN INVASIVE SPECIES

Convention on Biological Diversity (Nairobi, 1992) http://www.biodiv.org	*Article 8 (h). Parties to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species".*
Cartegna Protocol on Biosafety to the Convention on Biological Diversity (Montreal, 2000) http://www.biodiv.org	Protocol's objective is to contribute to ensuring adequate level of protection in the safe transfer, handling and use of living modified organisms resulting from modern biotechnology that may have adverse effects on the conservation and sustainable use of biological diversity.
United Nations Convention on the Law of the Sea (Montego Bay, 1982) http://www.un.org/Depts/los/losconv1.html	*Article 196. States to take all measures necessary to prevent, reduce and control the intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes.*
Convention on the Law of Non-navigational Uses of International Watercourses (New Work, 1997) http://www.un.org	*Watercourse States shall take all necessary measures to prevent the introduction of species, alien or new, into an international watercourse. (Article 22).*
Plant Protection Agreement for the Asia and Pacific Region (Rome, 1956) http://www.fao.org/legal/treaties	Contracting Governments to prevent the introduction into and spread within the South East Asia and Pacific Region of plant diseases and pests. A supplementary agreement under Article III of the IPPC.
Agreement for the Establishment of the Near East Plant Protection Organisation (Rabat, 1993) http://www.fao.org/legal/treaties	Promotes implementation of the provisions of the IPPC with particular attention to measures for the control of pests, and advises Governments on the technical, administrative and legislative measures necessary to prevent the introduction and spread of pests of plants and plant products.
International Health Regulations (Geneva, 1982) (adopted by the 22nd World Health Assembly in 1969 and amended by the 26th World Health Assembly in1973, and the 34th World	To ensure maximum security against the international spread of diseases with a minimum interference with world traffic. Regulations strengthen the use of epidemiological principles as applied internationally, to detect, reduce or eliminate the sources from which infection spreads, to

Health Assembly in 1981) http://www.who.int/emc/IHR/int_regs.html	improve sanitation in and around ports and airports, to prevent the dissemination of vectors and to encourage epidemiological activities on the national level.
IUCN-Guidelines for the Prevention of Biodiversity Loss Caused by Alien Invasive Species (2000) http://www.iucn.org/themes/ssc/pubs/policy/invasivevseng.html	Guidelines designed to increase awareness and understanding of the impact of alien species. Provides guidance for the prevention of introduction, re-introduction, and control and eradication of alien invasive species.
Guidelines for the Control and Management of Ships´ Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens. (Resolution A.868 (29)1997, International Maritime Organisation) http://www.imo.org	Provides guidance and strategies to minimize the risk of unwanted organisms and pathogens from ballast water and sediment discharge. Revokes the *"Guidelines for preventing the Introduction of Unwanted Organisms and Pathogens from Ships' Ballast Water and Sediment Discharges"* (IMO Resolution A.774 (18) 1991).
Agenda 21 – United Nations Conference on Environment and Development (Rio, 1992)	Calls for increasing protection of forests from disease and uncontrolled introduction of exotic plant and animal species 11.14); *acknowledgement that inappropriate introduction of foreign plants and animals has contributed to biodiversity loss and continues (15.3); appropriate rules on ballast water discharge to prevent spread of non-indigenous organisms.* 17.30(vi)); controlling noxious aquatic species that may destroy other aquatic species (chap. 18- 40(e)(iv)).
Code of Practice on the Introductions and Transfers of Marine Organisms (ICES/EIFAC 1994)	Recommends practices and procedures to diminish risks of detrimental effects from marine organism introduction and transfer, including those genetically modified. Requires ICES members to submit a prospectus to regulators, including a detailed analysis of potential environmental impacts to the aquatic ecosystem.
Code of Conduct for the import and release of exotic biological control agents (FAO, 1995) http://www.fao.org	Aims to facilitate the safe import, export and release of such agents by introducing procedures of an internationally acceptable level for all public and private entities involved, particularly where national legislation to regulate their use does not exist or is inadequate. Outlines specific responsibilities for authorities of an exporting country, who should ensure that relevant regulations of the importing country are followed in exports of biological control agents.
Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (UNEP, 1995) http://www.unep.org/unep/gpa/pol2a.htm	Introduction of Alien Species acknowledged to have serious effects upon ecosystem integrity.

Source: Shine, C., N. Williams, and L. Gündling (2000) ;(Mc Neely et al.,2001)

CONCLUSION AND RECOMMENDATIONS

India needs to devise clear and stringent policy on Invasive Alien Species, assessment of landscape dynamics in an intensive manner and detailed research for practical solutions, by coordinating with different research organization/institutions along with public participation is needed.

- To better monitor and control the most possible routes by which species arrive, as well as enable a risk assessment of potential invasive species prior to introduction, we need a coordinated national effort to inventory and document invasive species, not just a list of alien species, but also the pathways by which they were introduced. This comprehensive documentation would also enable pre-emptive assessment of alien species yet to become invasive (Hiremath and Krishnan, 2016).

- Role of remote sensing and GIS: For assessment of invasive species, mapping the extent of species invasion can be achieved using Geographical Information System, remote sensing and time series analysis. Adhikari *et al.*, (2015) illustrated the usefulness of open source data and software in generating a knowledge base having practical implications of IAS management by understanding and analyzing the alien species invasion problem which will provide guidance during the formulation of an effective policy and management strategy for controlling the invasive alien species in the country.

- In addition, we also have to protect our Protected Areas from the serious scourge of invasive species; therefore there is an urgent need to relook at the policies governing PA management in the country.

  Comprehensive international and national action is required: Numerous global and regional policies are already addressing the problem of IAS. Coordination of implementation and practical co-operation among those responsible for these instruments however, are highly insufficient. Practical prevention, eradication and control measures are also inadequate. We therefore recommend a consolidated action plan. The Convention on Biodiversity (CBD) and the International Plant Protection Convention (IPPC) could take the lead, but trade, transport, travel, and other economic sectors must be closely involved. Other institutions, including the United Nations Environment Programme (UNEP), the World Trade Organisation (WTO), Food and Agriculture Organisation (FAO), and the International Maritime Organisation (IMO) are key components at the international level. These institutions are supported by international non-governmental organizations (NGOs) such as The World Conservation Union (IUCN), World Wildlife Fund (WWF), Wetlands International, Conservation International, and The Nature Conservancy (TNC).

  Likewise, at the national level, consolidated and coordinated action is required. This could be part of a National Biodiversity Strategy and Action Plan, with close involvement of the economic sectors and identifying people responsible for operative actions involving potential IAS as a key prerequisite. Clear responsibilities for each relevant sector should be identified.

  - Insurance mechanisms and liability of regulations for the spread of IAS are almost non-existent, presenting a major deficiency for controlling the problem. Governments should cooperate with the insurance sector to find solutions, beginning with feasibility studies.

  - Capacity and expertise to deal with IAS are highly insufficient in many countries. Capacity building and further research on the biology and control of IAS and biosecurity issues should therefore be given attention and priority. This also relates to financial institutions and other organisations responsible for environment and development co-operation, at national and international levels.

  - A National information system regarding the biology and control of IAS is urgently needed. Tools, mechanisms, best management practices, control techniques and resources should be provided and exchanged.

- Awareness raising and education regarding IAS should be given high priority in action plans, and development of economic tools and incentives for prevention are urgently needed.

It is high time now to examine challenges posed by invasive species in India, take stock of the state of invasive species management, policy and practice and provide suggestions citing global best practices Hence if government agencies, universities, and government and non-governmental research institutes join hands and are serious about trying to meet up our national target on invasive species by 2020 (Hiremath and Krishnan, 2016).

REFERENCES

Adhikari, D., Tiwary, R. and Barik, S.K. (2015). Modelling Hotspots for Invasive Alien Plants in India. PLOS One, 10(7).

Chenje, M., and Mohamed-Katerere, J. C. (2006). Invasive Alien Species. In J. C. Mohamed Katerere, S. Mayar and H. Editorial (Eds.), Africa Environment Outlook 2. Our Environment, Our Wealth (pp. 331-349). Nairobi, Kenya: United Nations Environment Programme.

Hiremath, A and Krishnan Siddhartha (2016). India Knows Its Invasive Species Problem But This Is Why Nobody Can Deal With it Properly. The Wire.

Priyanka, N. and Joshi, P. K. (2013). A review of *Lantana camara* studies in India. International Journal of Scientific and Research Publications, 3(10): 1-11.

Shine, C., Williams, N. and Gundling, L.(2000). A Guide to Designing Legal and Institutional Frameworks on Alien Invasive Species. IUCN Gland, Switzerland, Cambridge and Bonn.

McNeely, J.A., Mooney, H.A. Neville,L.E., Schei,P. and J.K.Waage (eds.) (2001). A Global Strategy on Invasive Alien Species. IUCN Gland, Switzerland, and Cambridge, UK. x + 50 pp.

Wittenberg, R.et al. (2001). In global invasive species programme (GISP)(Eds.). Invasive alien species: A toolkit of best prevention and management practices, CABI,68 (228).

WEBSITE VISITED

- https://thewire.in/environment/invasive-species-prosopis-lantana
- https://www.downtoearth.org.in/coverage/invasive-alien-species-10861
- https://www.business-standard.com/article/news-ians/invasive-alien-species-eradication-underfunded-in-india-117040700920_1.html
- https://www.cbd.int/decision/cop/?id=7197.
- https://www. iucn.org/theme/species/our-work/invasive-species

ANNEXURE: 1. Invasive Alien Plant Species of India

Sl.no.	Species	Family	Habit	Place of origin	Reference	Common name
1.	*Acacia dealbata* Link	Fabaceae	Tree	South east Australia	Sekar (2012); Based on field observation by experts	Silver wattle
2.	*Acacia decurrens* (J.C.Wendl.) Willd.	Fabaceae	Tree	South east Australia	Based on field observation by experts	Green Wattle
3.	*Acacia mearnsii* De Wild.	Fabaceae	Tree	South east Australia	Sankaran *et al.*, (2013); Naithani *et al.*, (2017); Sekar (2012); Reddy *et al.*. (2008).	Black Wattle
4.	*Ageratina adenophora* (Spreng.) R.M.King & H.Rob.	Asteraceae	Herb	Trop. America	Holm *et al.*. (1991); Trounce and Dyason, (2003).	Sticky snakeroot Crofton weed
5.	*Ageratum houstonianum* Mill.	Asteraceae	Herb	Trop. America	Barua *et al.*, (2013); Sharma, (1987).	Floss Flower
6.	*Alternanthera philoxeroides* (Mart.) Griseb.	Amaranthaceae	Herb	Trop. America	Sekar, (2012).	Alligator weed
7.	*Antigonon leptopus* Hook. & Arn.	Polygonaceae	Climber	Trop. America	Sekar (2012);	Sandwich Island Creeper Coral Creeper. Coral Vine, Corallita Mexican Coral Vine, Mexican creeper, Pink Vine
8.	*Bidens pilosa* L.	Asteraceae	Herb	Trop. America	Muniappan and Viraktamath, (1993);Sekar et.al., (2012); Divakara, (2013)	Devil's Needles Hairy beggarticks
9.	*Centrosema molle* Mart. ex Benth.	Fabaceae	Herb	Mexico and Central America	Sankaran *et al.*, (2013); Based on field observation by experts	Butterfly-pea
10.	*Cestrum aurantiacum* Lindl.	Solanaceae	Shrub	North and South America	Sankaran *et al.*, (2013); Based on field observation by experts	Orange cestrum
11.	*Cestrum nocturnum* L.	Solanaceae	Shrub	Mexico to Venezuela.	Based on field observation by experts	Night-blooming jasmine

12.	*Chromolaena odorata* (L.) R.M.King & H.Rob.	Asteraceae	Herb	Trop. America	Gautier, 1992; Reddy *et al.*, 2008;Sankaran *et al.*, (2013); Mandal and Joshi, (2014); Naithani *et al.*, (2017)	Siam Weed, Christmas Bush Bitter Bush
13.	*Cytisus scoparius* (L.) Link	Fabaceae	Herb	Europe	ILDIS, (2003); Reddy *et al.*, (2008).	Scotch broom
14.	*Ipomoea carnea* Jacq.	Convolvulacea e	Shrub	Trop. America	Sekar, (2012); Reddy *et al.*,(2008)	Bush Morning Glory, Shrub Ipomoea
15.	*Lantana camara* L.	Verbenaceae	Herb	Trop. America	Burkill, (1935); Rawat, (1997); Gujral and Vasudevan, (1983); Sinha and Sharma, (1984); Nair and Henry. (1983); Sekar, (2012); Reddy *et al.*, (2008)	Wild Sage, Lantana, Shrub verbena
16.	*Leucaena leucocephala* (Lam.) de Wit	Fabaceae	Herb	Trop. America	Ghate, (1991); Binggeli, (1997); ILDIS, (2007); Reddy *et al.*, (2008)	Subabul, Lead tree, Leucaena, White lead tree
17.	*Mesosphaerum suaveolens* (L.) Kuntze (*Hyptis suaveolens* (L.) Poit.)	Lamiaceae	Herb	Trop. America	Based on field observation by experts	Wild Spikenard
18.	*Mikania micrantha* Kunth	Asteraceae	Climber	Trop. America	Gogoi (2001); Sankaran and Srinivasan, (2001); Reddy *et al.*, (2008); Lahkar *et al.*, (2011); Sekar, (2012).	Climbing Hempweed, Bittervine, Chinese Creeper
19.	*Mimosa pudica* L.	Fabaceae	Herb	Brazil	Reddy *et al.*, (2008); Sekar, (2012); Gehlot *et al.*, (2013)	Touch Me Not, Sensitive plant Humble plant
20.	*Mimosa diplotricha* C.Wright (Mimosa invisa C. Mart.)	Fabaceae	Scrambling shrub	South and Central America, Caribbean	Based on field observation by experts	Creeping sensitive plant Giant sensitive plant

21.	*Maesopsis eminii* Engl.	Rhamnaceae	Tree	West and Central Africa	Sankaran *et al.*, (2013)	Umbrella tree
22.	*Muntingia calabura* L.	Muntingiaceae	Shrub or Tree	Southern Mexico, Caribbean, Central America, and western South America	Based on field observation by experts	Jamaican cherry
23.	*Myriophyllum aquaticum* (Vell.) Verdc.	Haloragaceae	Herb	South America	Arshid, *et al.*(2011); Shah, *et al.*, (2014).	Parrot's feather
24.	*Parthenium hysterophorus* L.	Asteraceae	Herb	Trop. North America	Holm *et al.*, (1991); Gunaseelan, (1998); Singh and Kaur, (1997); Reddy *et al.*, (2008); Sekar, (2012); Sankaran *et al.*, (2013); EPPO, (2014); Srivastava *et al.*, (2014).	Feverfew, Santa maria fever few, Carrot Grass
25.	*Pontederia crassipes* Mart. (*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	Herb	Trop. America	Gopal, (1987); EPPO, (2014); Reddy *et al.*, (2008).	Water hyacinth
26.	*Prosopis juliflora* (Sw.) DC.	Fabaceae	Shrub	Mexico	Tewari *et al.*,(2000) ; Pasiecznik *et al.*, (2001); Harris *et al.*, (2003); Dayal, (2007); Anoop, (2010); Reddy *et al.*, (2008); Kaur *et al.*, (2012). Sekar, (2012); Singh *et al.*, (2015); ILDIS, (2017).	Vilaiti Keekar, Velvet mesquite, Algaroba
27.	*Salvinia molesta* D.Mitch.	Salviniaceae	Free-floating fern	Brazil	Nair, and Pai, (1973); Thomas(1979); Jayanth, (1987).	Butterfly fern
28.	*Senna spectabilis* (DC.) Irwin & Barneby	Fabaceae	Tree	Tropical America	Sankaran *et al.*, (2013); Based on field observation by experts	Calceolaria shower
29.	*Solanum elaeagnifolium* Cavanilles	Solanaceae	Herb	North-east Mexico and South-west USA	Based on field observation by experts	Silverleaf nightshade

30.	*Solanum mauritianum* Scop.	Solanaceae	Tree or Shrub	South America	Based on field observation by experts	Bugweed
31.	*Tagetes minuta* L.	Asteraceae	Herb	Brazil to S. South America.	Based on field observation by experts	Mexican marigold; stinkweed; wild marigold; stinking Roger
32.	*Ulex europaeus* L.	Fabaceae	Shrub	Western Europe	Reddy *et al.*, (2008); Naithani *et al.*, (2017).	Common Gorse

Note: Some plant species which are reported as invasive in other countries are not currently invasive in India and invasion of such species needs to be monitored in the country.

SOME OF INVASIVE ALIEN PLANT SPECIES OF THE COUNTRY

Ageratina adenophora (Spreng.) R.M.King & H.Rob

Ageratum houstonianum Mill.

Cytisus scoparius (L.) Link

(Photo credit: Dr. S.P.Subramani, IFGTB, Coimbatore)

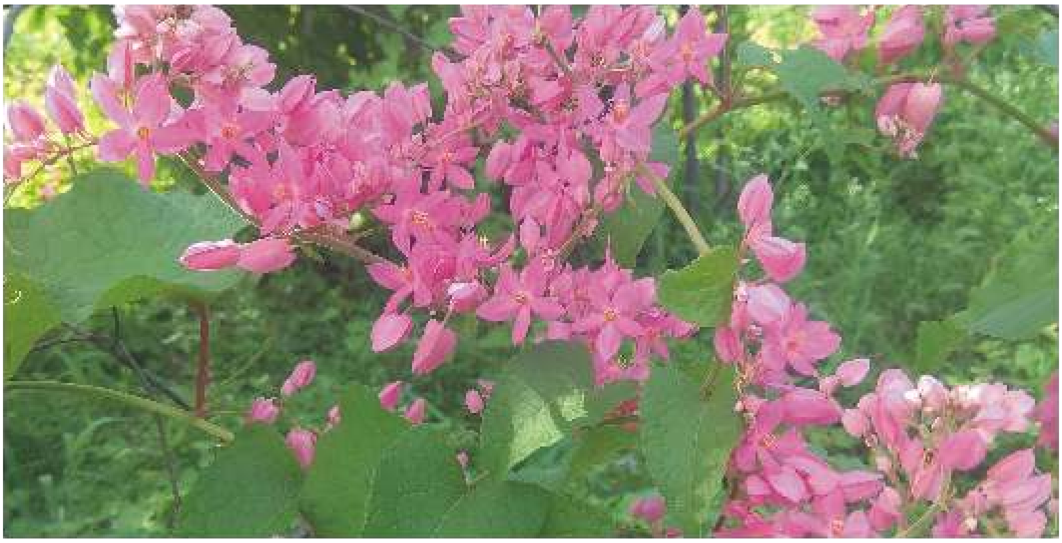
SOME OF INVASIVE ALIEN PLANT SPECIES OF THE COUNTRY

Ulex europaeus L.

Ipomoea carnea Jacq.

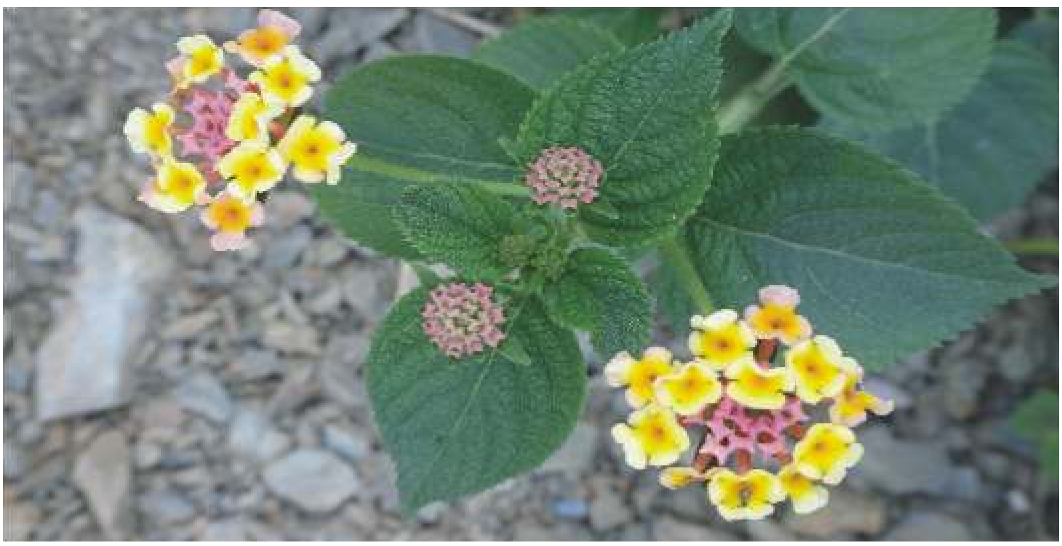
Pontederia crassipes Mart.

(Photo credit: Dr. S.P.Subramani, IFGTB, Coimbatore)



Antigonon leptopus Hook. & Arn.

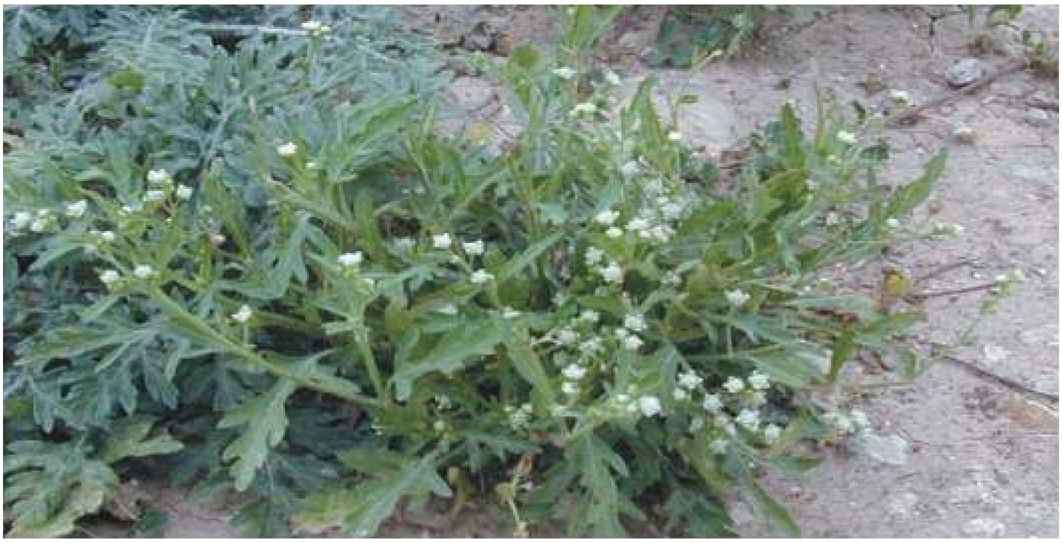
Cestrum aurantiacum Lindl.



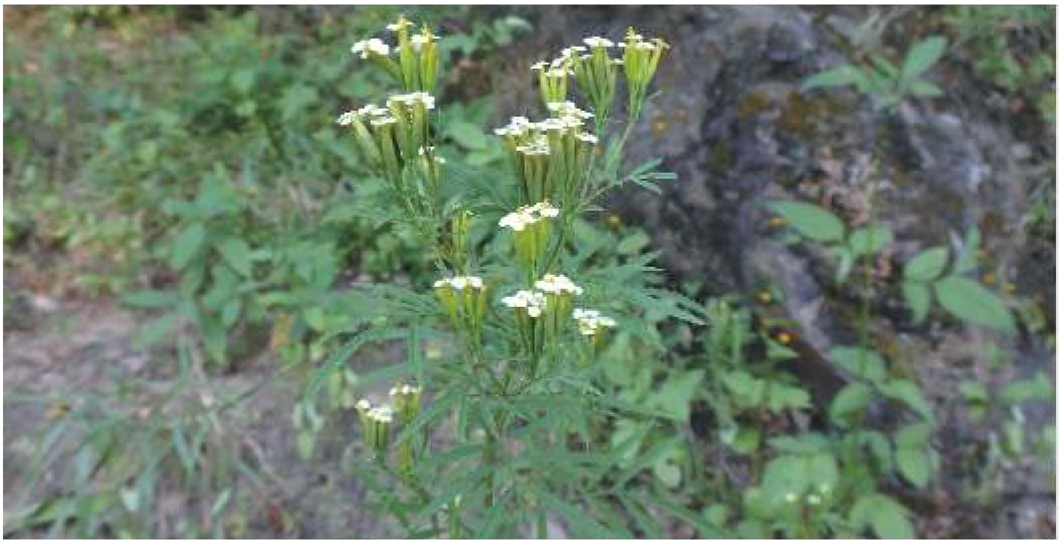
Lantana camara L.

(Photo credit: Dr. A. Rajasekaran, IFGTB, Coimbatore)

Mikania micrantha Kunth



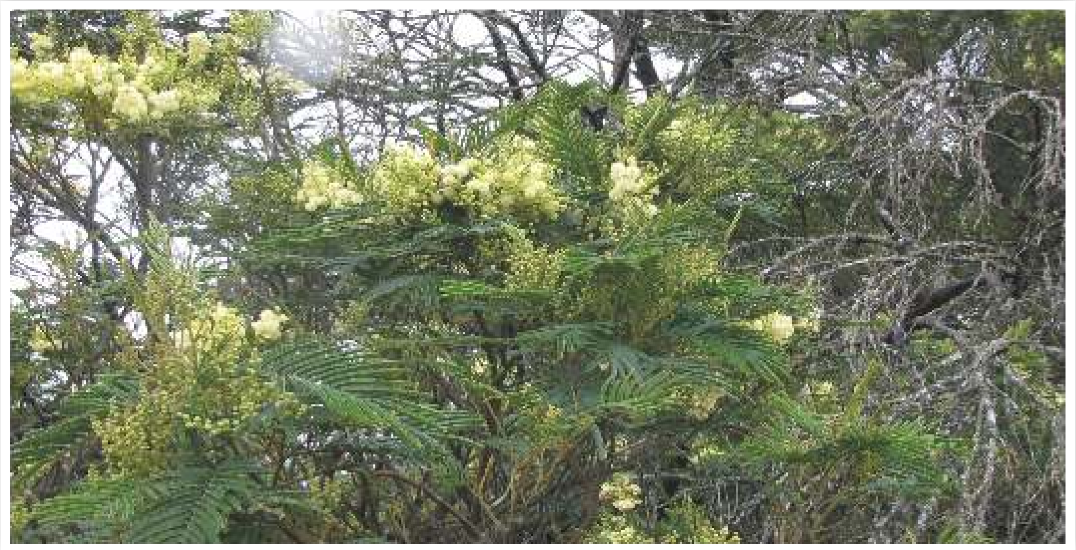
Parthenium hysterophorus L.



Tagetes minuta L.

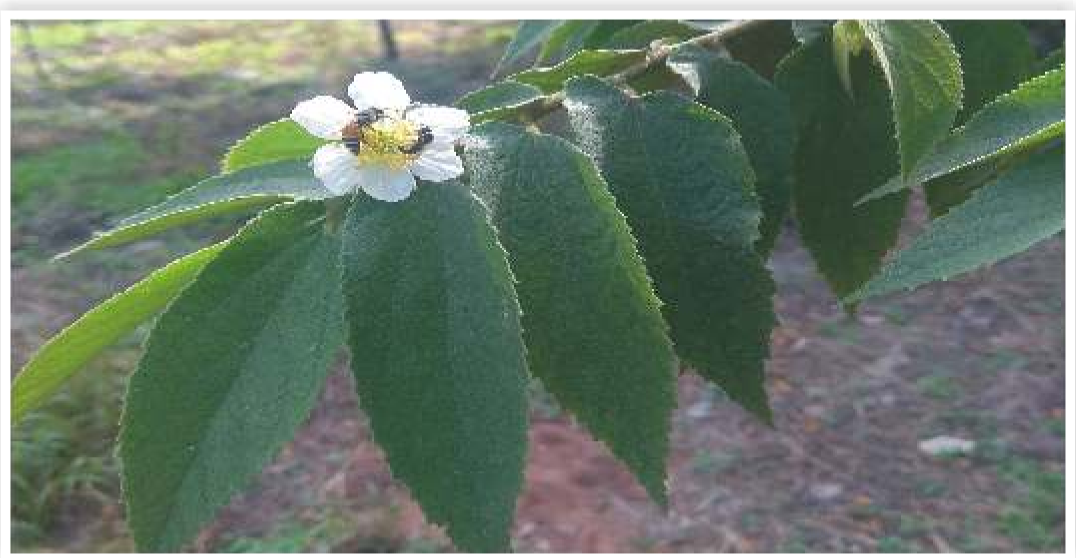
(Photo credit: Dr. A. Rajasekaran, IFGTB, Coimbatore)

SELECTED INVASIVE ALIEN TREES AND SHRUB SPECIES



Acacia mearnsii De Wild.

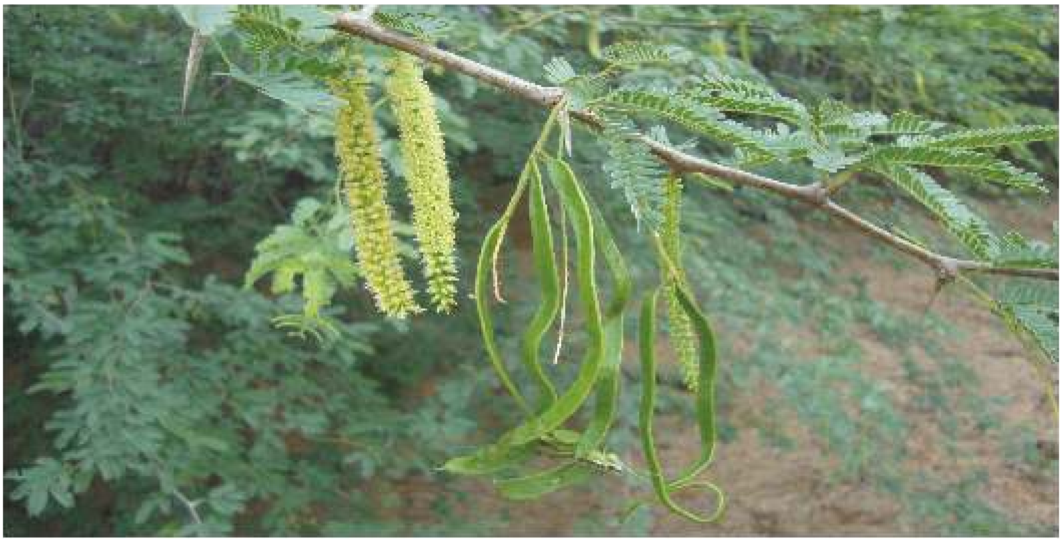
Leucaena leucocephala (Lam.) de Wit



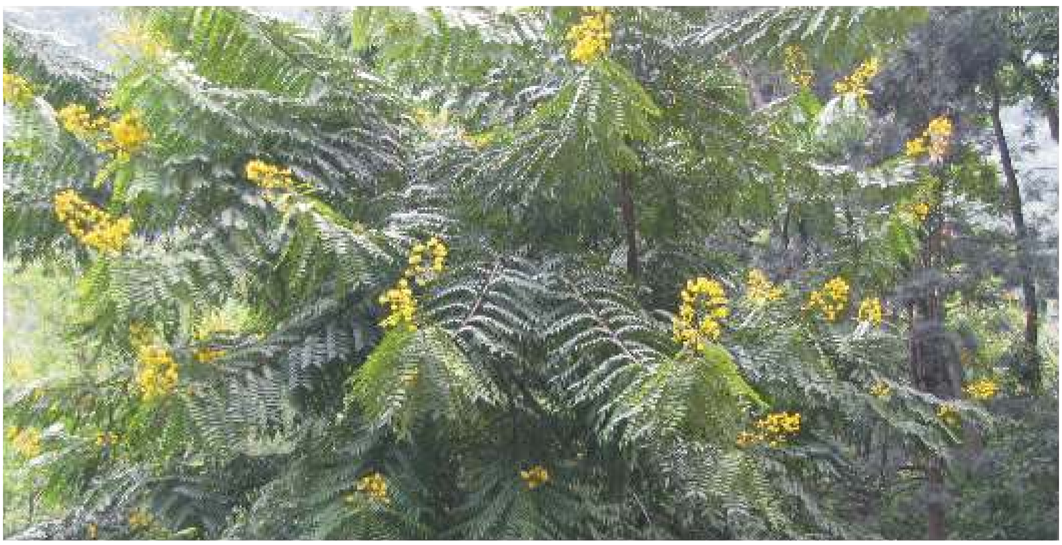
Muntingia calabura L.

(Photo credit: Dr. A. Rajasekaran, IFGTB, Coimbatore)

SELECTED INVASIVE ALIEN TREES AND SHRUB SPECIES



Prosopis juliflora (Sw.) DC



Senna spectabilis (DC.) Irwin & Barneby

Solanum mauritianum Scop.

(Photo credit: Dr. A. Rajasekaran, IFGTB, Coimbatore)

INVASION OF EICHORNIA CRASSIPES AND MIMOSA DIPLOTRICHA

Pontederia crassipes (*Eichhornia crassipes*) invasion in Kaziranga National park, Assam

Mimosa diplotricha invasion in Kaziranga National park, Assam

(Photo source: Dr. Dhruba J. Das, RFRI, Jorhat)

INVASION OF MIKANIA MICRANTHA

(Photo source: Dr. K. N. Baruah, RFRI, Jorhat)

Mikania micrantha invasion

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